2020-06

A CASE STUDY ON THE IMPACTS OF COST ESTIMATING WITHIN ACQUISITION PROGRAM DECISION-MA

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http://hdl.handle.net/10945/65561

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL PROJECT

A CASE STUDY ON THE IMPACTS OF COST ESTIMATING WITHIN ACQUISITION PROGRAM DECISION-MAKING

June 2020

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2020	**3. REPORT TYPE AND DATES COVERED** MBA Professional Project	
4. TITLE AND SUBTITLE A CASE STUDY ON THE IMPACTS OF COST ESTIMATING WITHIN ACQUISITION PROGRAM DECISION-MAKING			**5. FUNDING NUMBERS**
6. AUTHOR(S) Brady C. Juelson			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The use of cost estimating is critical to the continuation of acquisition programs due to full funding requirements. Cost estimates are developed and updated throughout the acquisition life cycle of nearly every defense acquisition program. This project analyzes all methods used by the Department of Defense for cost estimating and the trade-offs associated with each method. Understanding these methodologies, a real-life case study is developed based on the Joint Common Missile program and its cost estimates in order to facilitate the ability of acquisition professionals to analyze various cost estimates and understand the associated risks of cost estimating in order to make more prudent decisions or recommendations.

14. SUBJECT TERMS cost estimate, cost estimating, joint common missile, case study			**15. NUMBER OF PAGES** 87
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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A CASE STUDY ON THE IMPACTS OF COST ESTIMATING WITHIN ACQUISITION PROGRAM DECISION-MAKING

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
June 2020

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ABSTRACT

The use of cost estimating is critical to the continuation of acquisition programs due to full funding requirements. Cost estimates are developed and updated throughout the acquisition life cycle of nearly every defense acquisition program. This project analyzes all methods used by the Department of Defense for cost estimating and the trade-offs associated with each method. Understanding these methodologies, a real-life case study is developed based on the Joint Common Missile program and its cost estimates in order to facilitate the ability of acquisition professionals to analyze various cost estimates and understand the associated risks of cost estimating in order to make more prudent decisions or recommendations.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	acquisition category
AoA	analysis of alternatives
ASD	Assistant Secretary of Defense
APM	Assistant Product Manager
BY	budget year
CAB	cost analysis brief
CAIG	Cost Analysis Improvement Group
CAPE	Cost Assessment and Program Evaluation
CAPS	Counter Active Protection System
CARD	Cost Analysis Requirements Description
CBA	capabilities-based assessment
CCA	component cost analysis
CCE	component cost estimate
CDD	capability development document
CE	cost estimate
CET	Cost Estimate Team
CRBWG	Cost Review Board Working Group
CTD	concept and technology development
CTE	critical technology elements
DAB	defense acquisition board
DAE	Defense Acquisition Executive
DAS	defense acquisition system
DCAPE	Director, Cost Assessment and Program Evaluation
DOD	Department of Defense
DOTmLPF	doctrine, organization, training, materiel, leadership and education, personnel, and facilities
DT	developmental testing
EAC	estimate at completion
EdD	Doctorate of Education
EMD	Engineering and Manufacturing Development

EVM	earned value management
FRP DR	full rate production decision review
FY	fiscal year
GAO	Government Accountability Office
HBS	Harvard Business School
HEI	higher education institutions
ICE	independent cost estimate
ICD	initial capabilities document
IGCE	independent government cost estimate
JAGM	Joint-Air-to-Ground Missile
JCEL	*Journal of Cases in Educational Leadership*
JCIDS	Joint Capabilities Integration and Development System
JCM	Joint Common Missile
JCP	joint cost position
JROC	Joint Requirements Oversight Council
KPP	key performance parameters
LRIP	low-rate initial production
MBA	Master of Business Administration
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MDD	materiel development decision
MICA	McAleer interactive case analysis
MS	milestone
MSA	Materiel Solution Analysis
NAVAIR	Naval Air Systems Command
NCAD	Naval Cost Analysis Division
NCATE	National Council for Accreditation of Teacher Education
NDS	National Defense Strategy
NSS	National Security Strategy
O&M	operations and maintenance
PA&E	program analysis and evaluation
PEO	Program Executive Office

PO	Project Office
POE	program office estimate
PM	Product/program Manager
PMO	Project Management Office
PPBE	Planning, Programming, Budgeting, and Executing
RDECOM	Research, Development, and Engineering Command
RDT&E	research, development, test, and evaluation
SDRR	system definition and risk reduction
SA	systems analysis
SAR	System Acquisition Report
SAT	simplified acquisition threshold
SCA	service cost agency
SDD	system development and demonstration
STO	science and technology objectives
S&M	simulation and modeling
S&T	science and technology
T1	theoretical first
TDY	temporary duty
TM	tactical missile
TMRR	Technology Maturation and Risk Reduction
TOW	tube-launched, optically-tracked, wire-guided
TRL	technology readiness level
UK	United Kingdom
USA	United States Army
USMC	United States Marine Corps
USN	United States Navy
USD(A&S)	Under Secretary of Defense for Acquisition and Sustainment
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
WBS	work breakdown structure

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ACKNOWLEDGMENTS

I want to give special thanks to Dr. Mortlock, who took me under his wing after a simple handshake and hello. Thank you to Dr. Nussbaum for providing the expertise needed to decipher cost estimating at a deeper level. To my family, I am grateful for your enduring support through this process. I love you all immensely. Last, to the Soldiers and leaders who have impacted me throughout my career, I continue to serve due to your inspiration and professionalism.

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I. INTRODUCTION

This project is designed to produce an active learning environment through a case study to increase the capability of acquisition professionals, teachers, and students alike regarding cost estimating and the decision-making that cost estimates (CE) influence. The use of a case study allows for students and teachers to conduct social engagement that strengthens learning outcomes, increases individual performance, and amplifies emotional engagement relating to the effects of cost estimating (Nkhoma et al., 2017). The Joint Common Missile (JCM) is the program of record that is used for the case study due to the variance of its joint cost position (JCP) and the JCM independent cost estimate (ICE) produced by the Cost Analysis Improvement Group (CAIG). Both estimates were developed in preparation for the JCM's Milestone (MS) B Review with variances in schedules, technology maturation, and learning and production rate effects. Understanding these variances and their impacts on future costs is critical to the decision-making process used by a program manager (PM).

A. AFFORDABILITY DETERMINED THROUGH COST ESTIMATING

Affordability is always a major factor for procurement and in any defense acquisition program. Nearly all programs procured with taxpayer dollars for use within the Department of Defense (DOD) are constrained by budgeted dollars. Complicating things more are the "colors" of appropriated money. Given the complexity of defense acquisitions and their linkage to federal appropriations, program costs are heavily scrutinized throughout the entirety of the acquisition life cycle. Helping to reduce the complexity of the acquisition life cycle, CEs aid in decision-making along a program's timeline depending on the acquisition category (ACAT) of each program. Programs below the simplified acquisition threshold (SAT) are not required to produce CEs but often produce them to assist in decision-making.

According to Mislick and Nussbaum, CEs are a prediction of what the cost of future events will or should be. Cost estimating is the process of forecasting a future result in terms of cost and based upon information available at the time the estimate is made

(Mislick & Nussbaum, 2015). Cost estimates assist stakeholders with dollar-driven data needed to make timely and accurate decisions (R. Mortlock, PowerPoint slides, September 2019). CEs are typically needed at program initiation and all subsequent milestones, including the full rate production decision review (FRP DR; Parker, 2011). There are four methods that the DOD uses to develop cost estimates: analogy (top down), parametric (statistical), engineering (bottom up), and actual (extrapolation). Sometimes, due to lack of data or experience, expert opinion is also used as a method for cost estimating. It is important to note that most CEs are a composition of more than one method (Department of Defense [DOD], 2018a).

B. PROJECT ORGANIZATION

This project is built to allow the reader to understand the program of record being used and the basics of cost estimating. Background information on the JCM program as it relates to a hardware acquisition program traversing the Defense Acquisition System rounds the reader in the context of the case study. Additionally, cost estimating and its methods are reviewed as part of the acquisition life cycle. There is a literature review conducted on the importance of teaching through case study and the importance cost estimating has on the milestone decision reviews and program continuation/affordability decisions. The case study itself presents a scenario of an assistant program manager (APM) presented with multiple CEs that vary significantly in some areas but are relatively similar in total cost. Students must be capable of understanding the data within CEs to derive the inherent risks associated with the respective CEs. The ability for students to properly understand the risks associated with cost estimating is critical to the learning outcomes expressed through the discussion questions provided. Ultimately, with the appropriate data and background information, students will develop recommendations for the JCM PM as it relates to the CEs. Suggestions for this case study's teaching methodology are provided to support the format of the case study.

II. BACKGROUND

According to the *JCM Acquisition Strategy Report* (R. Mortlock, email to author, January 9, 2020), there became a growing need within the DOD to replace not only the depleted stocks of the Hellfire missile, but also the Hellfire missile itself, the tube-launched, optically-tracked, wire-guided (TOW) missile, and Maverick missile systems with just one missile system. Replacement of these missile variants meant integration of three types of seeker technologies and advancement of current missile technologies relating to propulsion as well as warhead capability. By integrating multiple technologies into one missile, the U.S. Army (USA) rotary-wing aircraft, the U.S. Navy (USN) and U.S. Marine Corps (USMC) rotary- and fixed-wing aircraft, and United Kingdom (UK) rotary-winged aircraft could execute a numerous and various array of missions with one common missile—the JCM (R. Mortlock, email to author, January 9, 2020).

A. THE JOINT COMMON MISSILE PROGRAM

The abundance of anti-tank missiles within the defense department was recognized at the congressional level in the late 1990s (CM PO, 2003). In response, the Program Executive Office Tactical Missiles (PEO TM) initiated and developed a business plan to address the congressional concerns. It was within this business plan that the PEO TM sought to bring the multiple seeker technologies into one delivery device, therefore reducing the amount of anti-tank missiles within the defense department's arsenal (Mortlock, 2005). Figure 1 shows the potential missiles replaced by the development of the JCM.

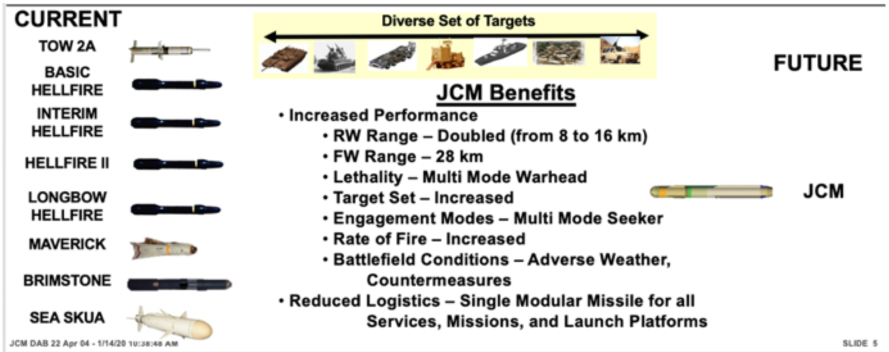


Figure 1. Anti-Tank Missiles Potentially Replaced by JCM. Adapted from R. Mortlock (personal communication, January 9, 2020).

1. JCM Program within the Acquisition Environment

According to the article, *The Joint Common Missile Project: Program Management Lessons Learned* (Mortlock, 2005), the JCM project office (PO) was established in October 2001 under the provisions of the streamlined acquisition principles, allowing the program to be tailored and therefore bypass or rapidly complete the Materiel Solution Analysis (MSA) phase due to independent yet mature technologies. The program's initial planned timeline brought the JCM to MS B in April 2004, a little more than two years after the PO's establishment. The acquisition environment and the decision support systems that guide acquisition programs through completion are depicted in Figure 2.

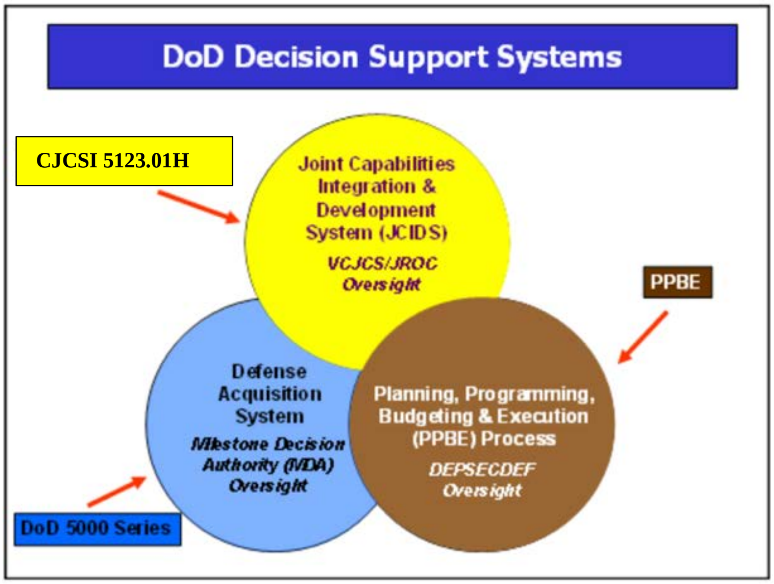


Figure 2. New DOD Acquisition Environment with the Addition of the Joint Capabilities Integration and Development System. Adapted from Defense Acquisition University (2013).

Shortly after its establishment, the JCM program was selected to become the first-ever program to traverse the Joint Capabilities Integration and Development System (JCIDS) process, which served as the JCM's genesis for key program documentation. Figure 3 depicts the JCIDS process by which appropriate requirements develop into three types of programs: "risk OK" circumscribes that no materiel solution will support the requirement submitted; "change in Doctrine, Organization, Training, materiel, Leadership and education, Personnel, and Facilities (DOTmLPF)" recommends a non-materiel change to the DOD to support the capability needed; and "gap validated," which leads to a materiel solution, or in this case, the JCM program (Rausch, 2019). For JCM, the requirement called for a multimodal, precision-guided air-to-ground missile with a multipurpose warhead and common motor to be fired from both rotary-wing and fixed-wing aircraft. Only a materiel solution through a development effort could meet this requirement, which resulted in an initial capabilities document (ICD), which was approved by the Joint Requirements Oversight Council (JROC).

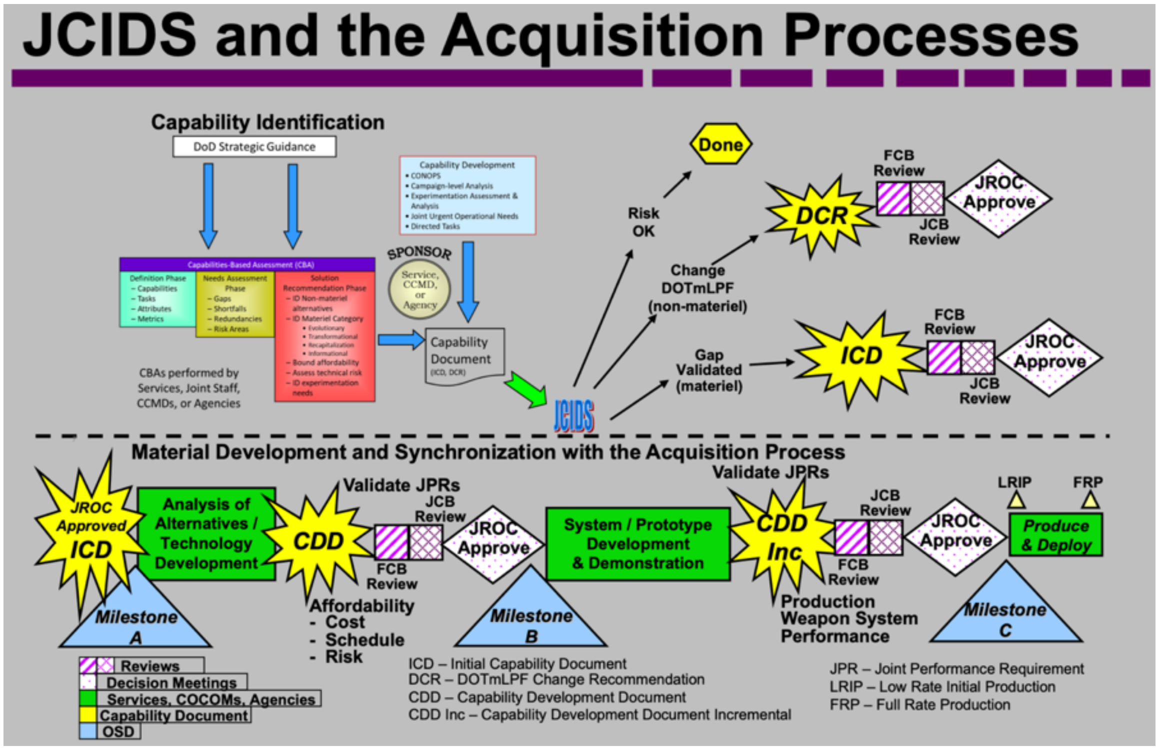


Figure 3. JCIDS Process. Source: Rausch (2019).

At the materiel development decision (MDD), the JCM program milestone decision authority (MDA) determined that the JCM should become a program of record and officially enter the acquisition framework at the MS B. This decision was based on the urgency of need, available resources, and technology maturity level of critical missile components (Mortlock, 2005). The JCM program had just finished a very successful three-year Technology Maturation and Risk Reduction (TMRR) phase, which met all exit criteria in which all critical technology elements (CTE) were assessed at technology readiness level (TRL) 6. Successful science and technology objectives (STO) efforts by Research, Development, and Engineering Command (RDECOM) preceded the TMRR phase. Comprehensive analysis during the TMRR phase underpinned the requirements for the JCM program.

Using Figure 4 to show the critical steps for the JCM program with respect to the capabilities requirements process, it is operating within the blue box and hopefully transitioning to EMD following a successful MS B DAB. The capabilities-based assessment (CBA) documented the need for JCM, along with an approved ICD. An approved analysis of alternatives (AoA) solidified the Joint Requirements Oversight Council (JROC)-approved capability development document (CDD) requirements, including the key performance parameter (KPP) thresholds/objectives.

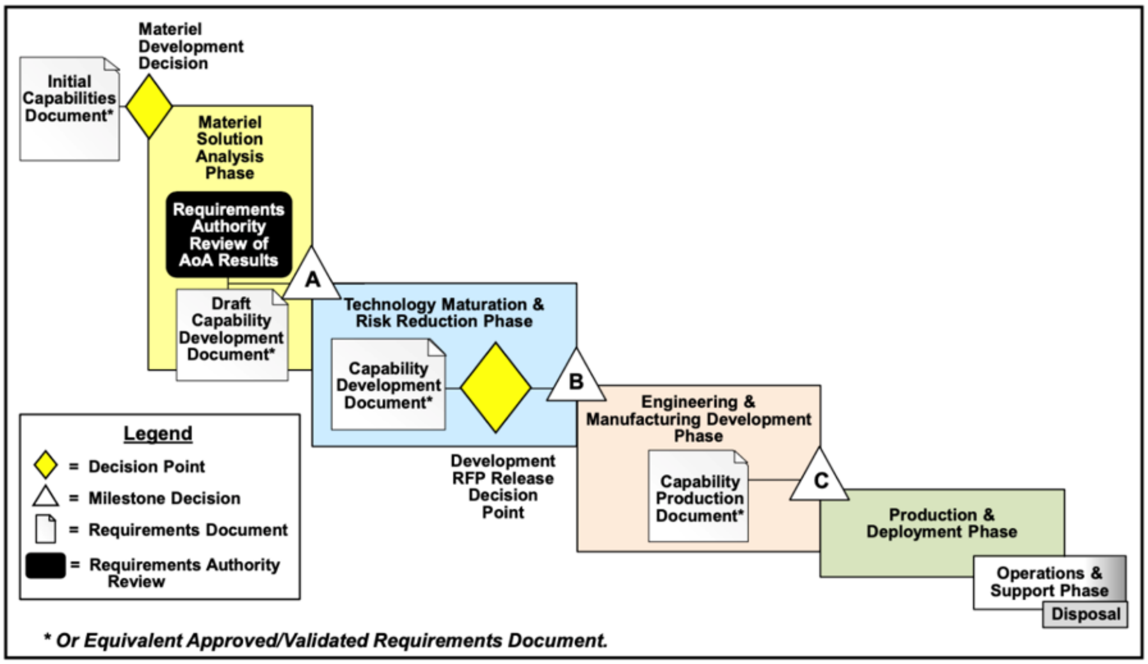


Figure 4. Capabilities Requirements Process. Source: Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S], 2020).

The second realm of decision support systems for defense acquisition represented in Figure 2 is the Defense Acquisition System (DAS). Here, the decision authorities vary depending on the acquisition category (ACAT) of the program. Due to the JCM being an ACAT ID (D refers to the defense acquisition board that advises the milestone decision authority [MDA]), the MDA for the JCM was the Undersecretary of Defense for Acquisition, Technology, and Logistics (OUSD[AT&L]).

Shown in Figure 5, the JCM program would operate within the hardware-centric acquisition framework. As the JCM PO established post-MS A and the CDD was validated through the JCIDS process, MS B became the next major decision point for the program.

In order to reduce risk in the TMRR phase, the PO emphasized that current technologies should focus on simulation and modeling (S&M). This deliberate process was critical to the program's ability to mitigate risk as it transitioned from numerous independent technologies into one system during Engineering and Manufacturing Development (EMD).

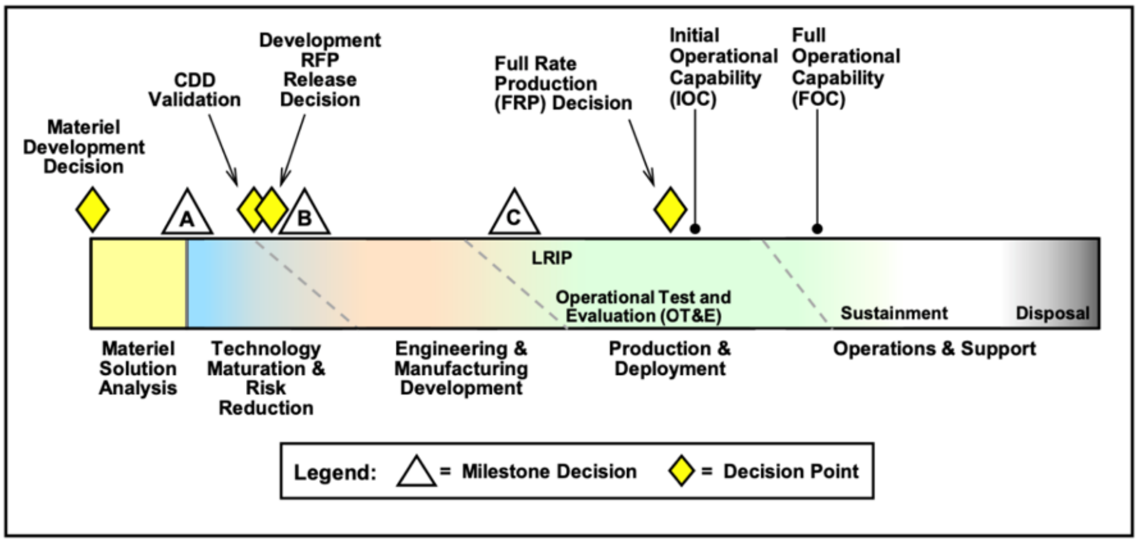


Figure 5. Defense Acquisition Program Model for a Hardware-Centric Acquisition Such as the JCM. Source: OUSD(A&S) (2020).

A benefit of the JCM program establishing post-MS A was the PEO TM's ability to leverage its already successful business plan ventures that supported the JCM program and the PEO TM. In doing so, the JCM program timeline depicted in Figure 6 represents a program that successfully negotiated a TMRR phase with a planned four-year EMD phase. In doing so, it also completed all JCIDS and JROC requirements and was postured for its Defense Acquisition Board (DAB) with the MDA at MS B.

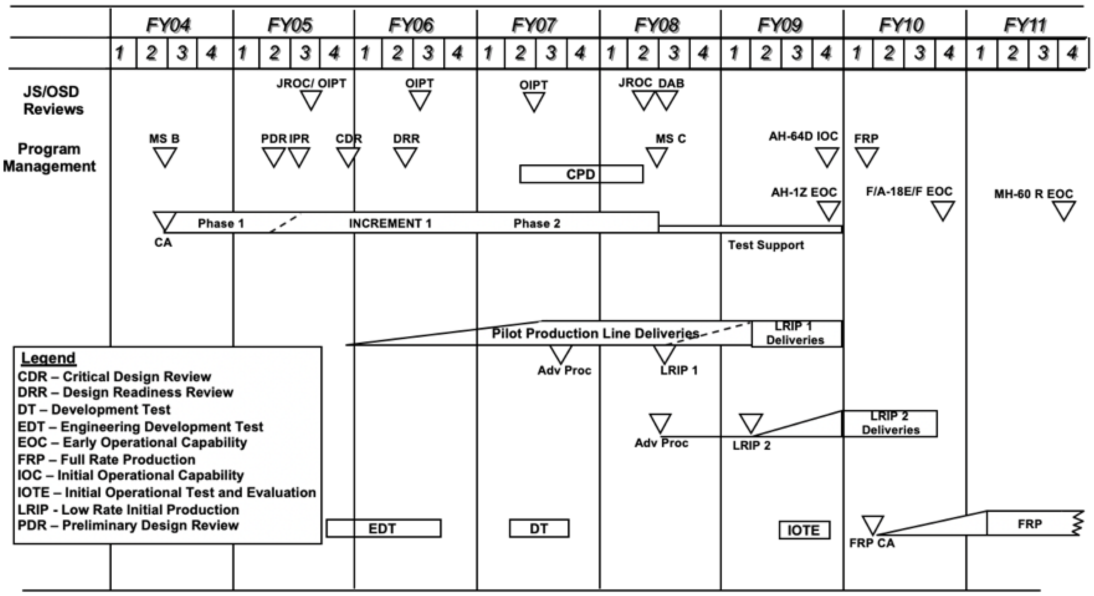


Figure 6. JCM Program Schedule. Source: R. Mortlock (personal communication, January 9, 2020).

The third and final realm of the decision support systems represented in Figure 2 is the planning, programming, budgeting, and execution (PPBE) process. The purpose of the PPBE process is to ensure that resources are properly allocated within the DOD to support the National Defense Strategy (NDS) and National Security Strategy (NSS) objectives. Even though broken down into four distinct phases, each phase is not mutually exclusive. It is within the PPBE process that all acquisition professionals rely heavily on cost estimates to inform decision-making and recommendations. Affordability becomes a central theme at every major decision point. Figure 7 represents where cost estimates are required for ACAT ID programs in order to inform decision-makers on future costs.

COST ESTIMATING REQUIREMENTS

	ACAT IC and ID (MDAP)	ACAT IAM and IAC (MAIS)
POE	Program initiation & all subsequent milestones, including FRP DR	Program initiation & all subsequent milestones
CARD	Program initiation & all subsequent milestones including FRP DR • Draft: 180 days prior to OIPT • Final: 45 days prior to OIPT	Program initiation & whenever Economic Analysis is required • Draft: 180 days prior to OIPT • Final: 45 days prior to OIPT
CCE	MS A and all subsequent milestones including FRP DR	MS A and whenever an Economic Analysis including is required
ICE	Required by law for all MDAP programs * • Prepared by OSD CAPE for ACAT ID, and ACAT ICat discretion of USD (AT&L) • Prepared by component cost agency (AFCAA,DASA-CE, NCCA) for ACAT IC (if no CAPE estimate) • In advance of any certification under Title 10, U.S.C., Section 2366a (MS A) and Section 2366b (MS B) • In advance of any decision to enter low-rate initial production (LRIP) (MS C) or full-rate production (FRP DR) • In advance of any certification of MDAPs that experience critical cost growth (Title 10, U.S.C., Sec 2433a) • In advance of any report of Critical Program Changes for MAIS (Title 10, U.S.C., Sec 2445c(f))	

*ICE statutory requirement (Title 10, US Code, Sec 2434) and P.L. 111-23, May 22, 2009

Source: DoDI5000.02, December 2008 and Weapon Systems Acquisition Reform Act of 2009

Figure 7. Cost Estimates Required along a Defense Acquisition Program Timeline. Adapted from Parker (2011).

Specifically, for the JCM program referenced in Figure 7, there are numerous cost-estimating requirements as the JCM program traverses the acquisition framework. The Program Office Estimate (POE), Cost Analysis Requirements Description (CARD), Component Cost Estimate (CCE), and ICE are all required for the defense acquisition board at MS B. The draft CARD developed for the JCM program was based on a notional design due to the program not having a specific contractor design. The CARD prepared for the JCM program was approved during the Cost Analysis Brief (CAB) and would influence the JCP and the ICE developed by the CAIG (R. Mortlock, email to author, November 14, 2019).

Further clarification from the JCM Acquisition Strategy Report (R. Mortlock, email to author, January 9, 2020) shows the genesis of the program's start post-Congressional concerns that sought a reduction in anti-tank missiles. The growing need by the services to upgrade existing air-to-ground missiles guided the Army, Navy, and Marines toward a common solution. Led by the Army, the JCM became the solution to both the need and subsequent requirements. During the TMRR phase of the defense acquisition framework, the JCM PO focused on the JCM's ability to incorporate independently mature technologies into one single system, as shown in Figure 8. It is with these collective technologies that the program faced dramatically different cost estimates to inform decision-making heading into the EMD phase. At the onset of MS B, a prototype of the JCM had yet to be flown (R. Mortlock, email to author, January 9, 2020).

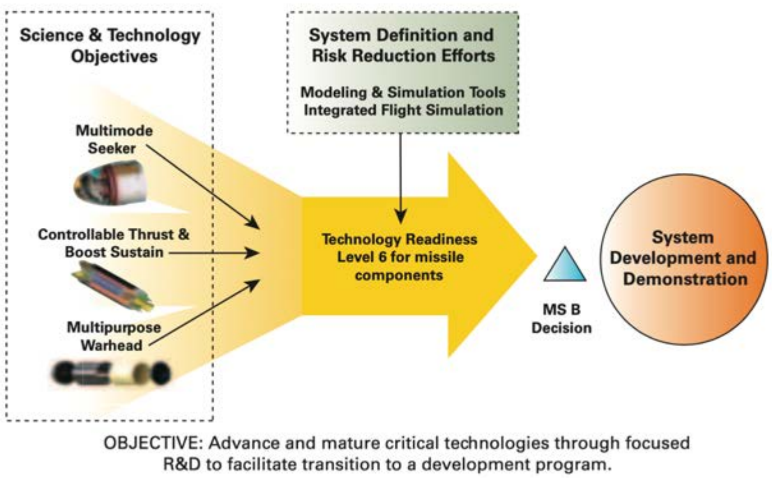


Figure 8. Independent Technology Integrated into the JCM. Source: Mortlock (2005).

2. JCM Joint Cost Position

According to the Cost Review Board Working Group (CRBWG), the JCM JCP was developed in preparation for MS B and later became the CE used by the defense acquisition executive (DAE) for the program entering into EMD (R. Mortlock, email to author, November 14, 2019). The JCP was a combination of updated POEs by both the Army and

Navy that was reconciled through the CRBWG. It combined the cost estimates of the Army's portion of the missile (all common components) and the Navy and Marine's CE relating to the Navy/Marine-specific components of the JCM. The JCP also served to document the methodologies used throughout the CE. In the case of the JCP, it utilized multiple CE methodologies, including analogy, parametric, engineering, and actuals, as well as expert opinion. The CRBWG developed the JCP from January 12–30, 2004, and used the approved original "notional" CARD. The estimated costs developed in the JCP broken down by "colors" of money is found in Table 1 (R. Mortlock, email to author, November 14, 2019).

Table 1. JCP JCM Life-Cycle Costs. Source: R. Mortlock (personal communication, November 14, 2019).

Cost Element		JCP		
		Army	Navy	Total
1.0	RDT&E	552	418	970
2.0	Procurement	2,162	3,861	6,023
4.0	Military Personnel	15	-	15
5.0	Operations and Maintenance	179	88	267
	Total Life Cycle Costs	2,908	4,367	7,275

This table uses Budget Year (BY) 2004 dollars in millions.

3. Cost Analysis Improvement Group Independent Cost Estimate for the JCM

Due to the statutory requirements outlined in Figure 7, the JCM program was required to produce an ICE in addition to the JCP. The CAIG ICE produced for the JCM program varied somewhat with the JCP. The CAIG'S ICE for the JCP is based on the updated CARD, dated March 23, 2004, roughly two months after the JCP was complete. The ICE and JCP variance of life-cycle costs are depicted in Table 2 (R. Mortlock, email to author, November 14, 2019).

Table 2. JCM ICE and JCP Life-Cycle Cost Comparison. Adapted from R. Mortlock (personal communication, November 14, 2019).

Cost Element		Cost Estimate Source		Difference
		JCP	CAIG	
1.0	RDT&E	970	1,350	380
2.0	Procurement	6,023	7,490	1,467
4.0	Military Personnel	15	20	5
5.0	Operations and Maintenance	267	270	3
	Total Life Cycle Costs	7,275	9,130	1,840

This table uses BY2004 dollars in millions.

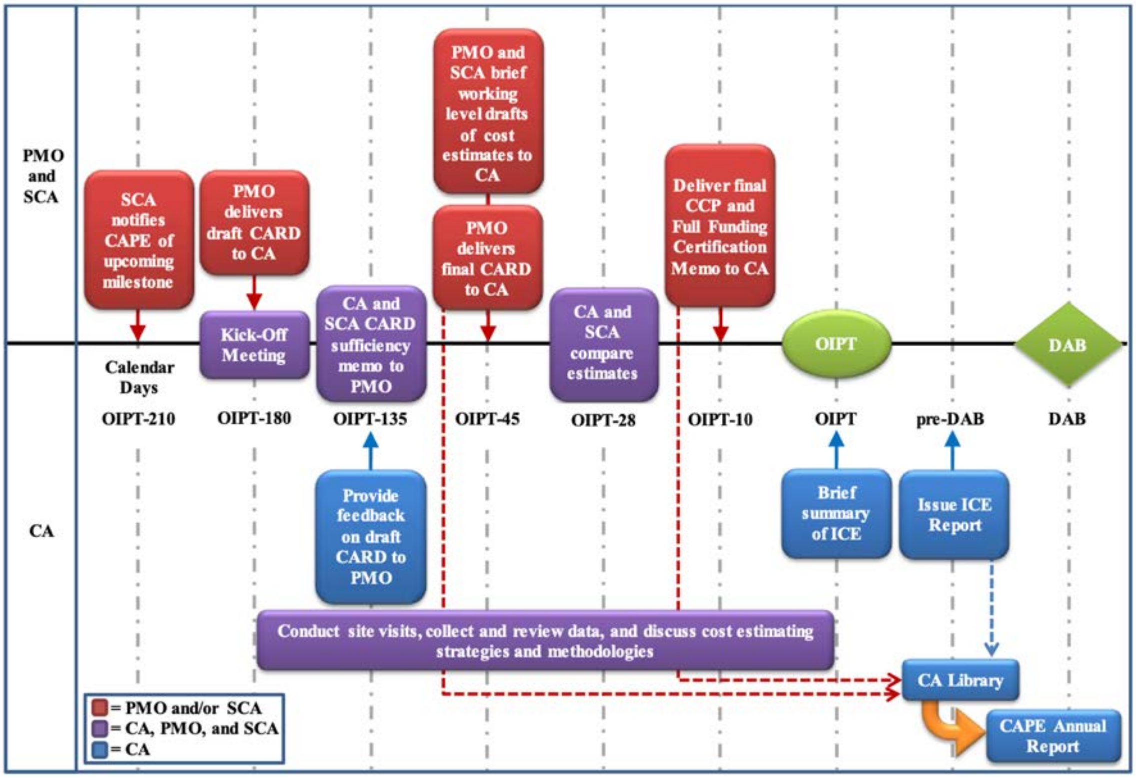
B. COST ESTIMATING

Navigating cost estimation within defense acquisition is equally as complex as the defense acquisition framework itself. The application of cost analysis and furthermore, cost estimating requires the understanding of a cost estimate's function within the acquisition framework as well as the methods used to produce these snapshots in time. Regardless of one's understanding, cost estimates are critical for effective MDA acquisition oversight and decision-making (Office of Cost Assessment and Program Evaluation [CAPE], 2017). The GAO guidebook states that cost estimates also serve to feed or support the cyclical federal budget cycle, impacting budget requests and proper alignment of resources, and seek to improve the financial performance of the DOD (Richey et al., 2009).

According to *Cost Estimation Methods and Tools* (Mislick & Nussbaum, 2015), there are some general principles for anyone seeking to use cost estimates as a method to assist in decision-making. The first is that cost estimates are *not* precise, but rather are thorough and complete, meaning they possess key characteristics: completeness, reasonableness, credibility, and analytical defensibility. Second, while a thorough and complete cost estimate may have been provided at the time the CE was developed, assumptions were made. Understanding the assumptions within the CEs is critical to sound decision-making moving forward as well as looking back at the CE's accuracy at a later date. Third, change will always occur. Tariffs on raw materials, a newly passed wage rate for the contractor's state of operation, congressional funding, and sequestration all impact the costs being estimated. Fourth, "cost issues are always a *major* concern, but they are almost never the *only* concern" (Mislick & Nussbaum, 2015, p. 4). Fifth, CEs are "guides" to enabling decision-makers, not the answer. And last, cost estimates are an amalgamation of people, processes, and the data. Each of these elements is a product of its time and likely to change as newer technology creates ways to capture and apply data, people receive higher levels of education, and newer ways to analyze the data become available (Mislick & Nussbaum, 2015).

1. Cost Estimating in Defense Acquisition

CAPE and its director (DCAPE) execute the statutory guidance and requirements found within DOD 5000.01 and DOD 5000.02 in order to guide acquisition professionals toward sound decision-making practices. There are three particular applications of cost estimating that CEs influence: long-term planning, budgeting, and choosing an alternative (Mislick & Nussbaum, 2015). All three of these broader categories are nested within the DAS, and the statutory requirements that necessitate the CEs are directly tied to one or more of these categories for decision-making. As a result of the requirements to influence broader objectives, CAPE is deliberately intertwined into the DAS to ensure compliance, as outlined in Figure 9.



PMO in this figure stands for project management office. SCA is the service cost agency or defense equivalent. CA is the office of Cost Assessment (CAPE). Timelines differ depending on ACAT.

Figure 9. CAPE and PMO Interaction for an ACAT ID Program. Source: CAPE (2017).

Using Figure 9 to simplify, the PMO not only contacts CAPE for support of major events, but it also develops the CARD used to facilitate the CEs. Before the PMO is authorized to begin its POE, the CARD must be deemed sufficient by CAPE. The final outputs required by the PMO include a completed POE and a full funding memorandum used to grant approval at the upcoming milestone. CAPE not only supports review of the CARD developed by the PMO, but it also produces the required ICE at major decision points. An independent government cost estimate (IGCE), or ICE, attempts to answer five primary questions in order to properly educate its audience while providing enough context so the data represented in the CE can be used by the various stakeholders within the program.

1. How was the estimate made?

2. What assumptions were made?

3. What information/tools were used?

4. Where was the information obtained from?

5. How did previous estimates compare with prices paid? (DOD, 2018a, p. 7)

These questions are intended to ensure the cost estimate developed has a clearly defined purpose and scope, partnered with a realistic schedule of completion. The purpose of the estimate is critical to informing the estimating team on the scope and schedule and is effectively the first critical step to developing a cost estimate. The Government Accountability Office (GAO) has outlined 12 steps that ensure the cost estimate is generated effectively. The steps of CE development are not a linear checklist process of steps but rather, an iterative process that constantly seeks to improve itself through analysis. Figure 10 details the 12 steps showing the ideal cost estimate production steps.

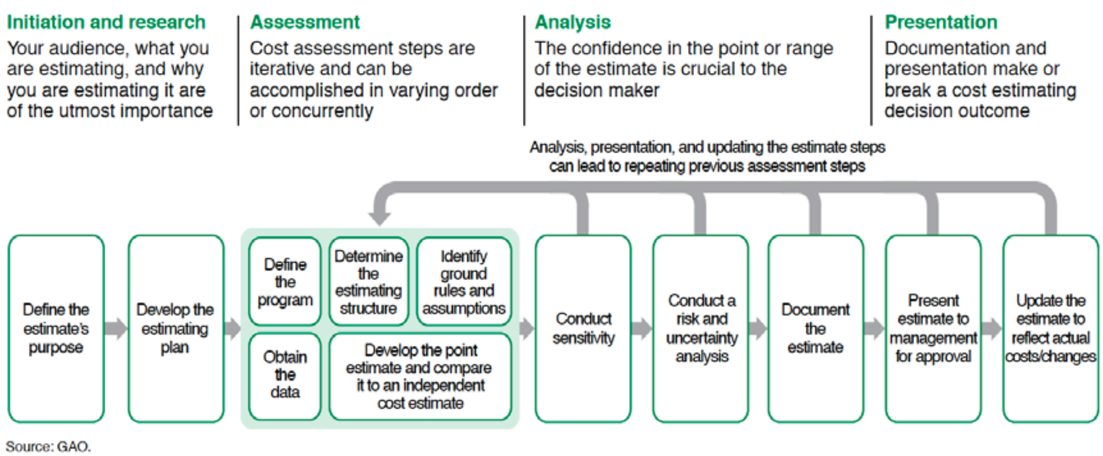


Figure 10. 12-Step Cost Estimate Process. Source: Richey et al. (2009).

2. Cost-Estimating Methods

The DOD utilizes four common methods and one ancillary method when needed to deliver CEs. Each method used carries different risks for the decision-maker regarding its utility as the program moves forward in time. Cost estimates are data points in time, but as the time elapses and actions are taken within the PMO, change in costs immediately ensue. Understanding the cost-estimation methods at a "greater than surface-level" understanding may effectively reduce a program's cost and schedule breach. Selecting the appropriate cost estimate methodology, and likely combination of methods, may likely yield the greatest quality cost estimate (NASA Cost Analysis Division, 2015). For this project, special attention is made with respect to the various assumptions regarding the JCM's improvement curves and production rates. Figure 11 shows where each method is likely used with respect to the program phases. This figure highlights the relationship between the cost-estimation method and the amount of detail an estimate may produce given the program's position across the life cycle.

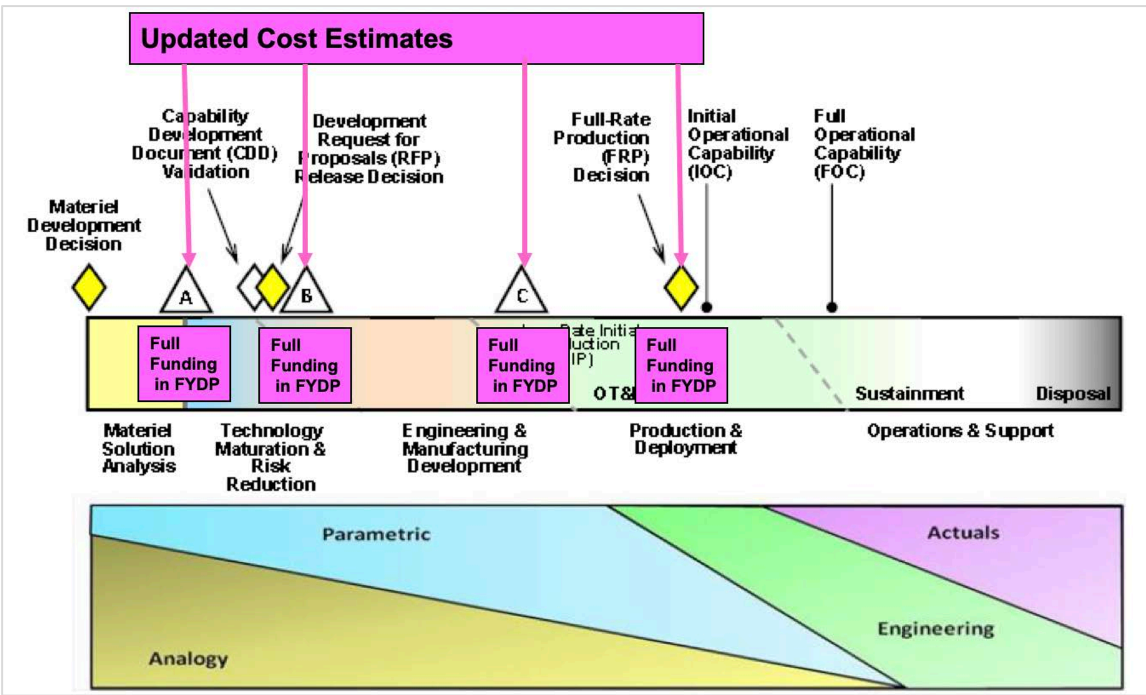


Figure 11. Cost Estimates Required and Methods Used. Source: R. Mortlock (personal communication, November 14, 2019)

a. Analogy

The analogy cost-estimating methodology is typically used early in a program's life cycle due to the lack of specific data relating to the actual program. With the lack of a clearly defined system, analogy cost estimating seeks to find a previously fielded system that is comparable and is an aspect that reliably drives cost, then baselines those costs subjectively and accepts the former program's costs as a basis for the estimate. This method often relies heavily on the expertise of the cost estimate team (CET) to subjectively adjust upward or downward depending on the complexity of the comparable systems (Richey et al., 2009).

b. Parametric

The *Parametric Estimating Handbook* (International Society of Parametric Analysts [ISPA], 2008)[1] is a complete guide to the application of what is considered the "top down" approach to cost estimating—parametric methodology. It uses statistical relationships between a few key pieces of data that are similar to the program being estimated. Understanding the cost drivers of similar programs enables the CET to develop a hypothesis to predict the future costs of the current program. This estimate method has a wide variety of applications and can be done as soon as the CET has a hypothesis as to the likely cost drivers of the current program. The historical data in comparison that used the same cost drivers is normalized before conducting a regression analysis. The regression analysis will determine whether the data used was a good fit for the comparison and if so, will then be applied to predict the costs of the new program (ISPA, 2008).

c. Engineering

Considered a "bottom up" estimate, the engineering cost estimate methodology requires significant amounts of data. Engineering CEs require a form of work breakdown structure (WBS) at the lowest levels, historical data of similar programs, and actual costs. Engineers intimately familiar with the work being analyzed assist the CET in developing the costs that are related to the CE. This method is typically used once a program has entered into production or after the program has gone through either a preliminary or

[1] IPSA merged with the Society of Cost Estimating and Analysis to become the International Cost Estimate and Analysis Association (ICEAA) in November 2012.

critical design review. By using the figures found in the program's designs, the CET then has enough data to support the engineering method. (ISPA, 2008).

d. Actuals

Often referred to as extrapolation from actual costs, this methodology uses the current program's costs to predict future costs of the same or like item(s). Average costs can and sometimes are used to predict the cost of future units. Estimates at completion (EAC) are also actual CEs using various earned value management (EVM) data points to predict terminal production costs. The most common actual cost estimates are those predicting costs through improvement curves, commonly known as learning curves. Estimating costs using "learning curve" theory can greatly reduce the predicted future cost of a program. Advancements in cost improvement theory have led to an added variable to the improvement curve calculations. That variable becomes the production rate, indicating the number of units produced during the period. Use of production rates to influence cost estimates is applicable where large production occurs at various rates, thus influencing the slope related to learning (ISPA, 2008).

e. Expert Opinion

Although entirely subjective in nature, expert opinion is used when necessary. Typically, expert opinion is leveraged when no historical data is available, although the CET must pay special attention to the expert's credibility and attempt to derive the source of the expert's opinion. This method is not synonymous with the expertise applied by the CET to develop cost estimates. Table 3 is a collection of strengths and weaknesses for the various methods according to multiple sources.

Table 3. Strengths, Weaknesses, and Applications of Contract Estimating Methodologies. Adapted from Richey et al. (2009) and NASA (2015).

Method	Strength	Weakness	Application
Analogy	• Requires little data • Based on actual data • Reasonably quick • Easily understood • Accurate for minor deviations from the analog	• Subjective adjustments • Accuracy depends on similarity of items • Difficult to assess effect of design change • Difficult to identify appropriate analog	• When few data are available • Rough-order-of-magnitude estimate • Cross-check • Long-range planning
Parametric	• Reasonably quick and can be replicated • Encourages discipline • Good audit trail • Objective, little bias • Cost driver visibility • Incorporates real-world effects (funding, technical, risk)	• Lacks detail • Model investment • Cultural barriers • Need to understand model's behavior • Loses predictive ability/ credibility outside its relevant range	• Budgetary estimates • Design-to-cost trade studies • Cross-check • Baseline estimate • Cost goal allocations • Design-to-cost trade studies
Engineering	• Easily audited • Sensitive to labor rates • Tracks vendor quotes • Time honored	• Requires detailed design • Slow and laborious • Cumbersome	• Production estimating • Software development • Negotiations
Actual	• Reliance on historical costs to predict future costs • Great credibility and reliability for estimating costs • Ability to be applied to any level of data	• Changes in the accounting of actual costs can be difficult • Results will be invalid if the production process or configuration are not stable • It should not be used for items outside the actual cost data range	• Best suited to be used when predicting costs of future items that have already been through production
Expert Opinion	• Can be used when no historical data are available • Takes minimal time and is easy to implement once experts are assembled • Can be blended with other estimation techniques	• Lack of objectivity • Risk that one expert will try to dominate a discussion • Not very accurate or valid as a primary estimating method	• Applicable in all acquisition phases

3. Unpacking Improvement Curve Theory and Production Rates

Due to the variance between the JCM's JCP and IGCE, this project aims to provide acquisition professionals with a better understanding of both improvement curve theory and production rate application as it relates to cost estimates. According to the CAIG ICE,

> The CAIG estimate of recurring production costs is based on a single, top-level recurring production curve with a learning rate of 88 percent and a production rate effect of 90 percent. The parameters of the CAIG production cost curve are based on the pooled results of 12 prior missile production programs. In contrast, the JCP recurring production cost estimate is built from a much lower level with separate T1s[2] and cost progress curves for each specific missile component. For example, the JCP for the millimeter wave seeker component employs learning and production rate effects of 89 percent and 85 percent respectively. Thus, the JCP does not employ a single aggregate-level production cost curve. For comparative purposes, we statistically determined that the JCP recurring production cost estimate is consistent with a 93 percent learning rate and an 83 percent [production] rate effect. The JCP estimate, therefore, implicitly places far more importance on production rate rather than cumulative learning. Also, we note that the production rate slope value used in the JCP is quite aggressive by historical standards, although not entirely unprecedented. (R. Mortlock, personal communication, November 14, 2019)

Synthesizing this quote, learning rates and production rates are directly linked, but the application of various rates of production may greatly change yearly budgeted dollars as depicted in the two JCM CEs.

a. Improvement Curve Theory

In *Better Business Decisions Using Cost Modeling for Procurement, Operations, and Supply Chain Professionals*, the example of performing a laborious task repetitively results in a reduced amount of time for future executions of the same task. Another example is the procurement of a new personal device. Initially a guide or instruction pamphlet is required by the user to perform basic tasks. The requirement of a pamphlet instruction guide is quickly discarded and the user is capable of performing nearly all functions without much thinking. This is learning curve theory in practice. The reduction in time per

[2] T1 is referring to the theoretical first unit produced. This is typically represented as a figure of cost.

repetition represents the learning rates. At 100%, no learning is applied to the task, while 80% rates of learning indicates a significant rate of learning for a repetitive process. The example of the personal device while simple, indicates the learning rate would closely resemble a rate at 80% rather than 100% (Sower & Sower, 2015). Figure 12 demonstrates a learning rate at 95% in the table, then from 95% to 85% in the chart plotting the curves.

Number of repetitions	Hours per repetition*	Reduction in hours per repetition
1	50.00	–
2	47.50	2.50
4	45.13	2.37
8	42.87	2.26
16	40.73	2.14
32	38.69	2.04
64	36.75	1.94

The values in this column can be calculated using a spreadsheet program such as Excel. To obtain the hours per repetition for two repetitions, type the following into a cell in Excel: =50.95. The result will be displayed as 47.5.

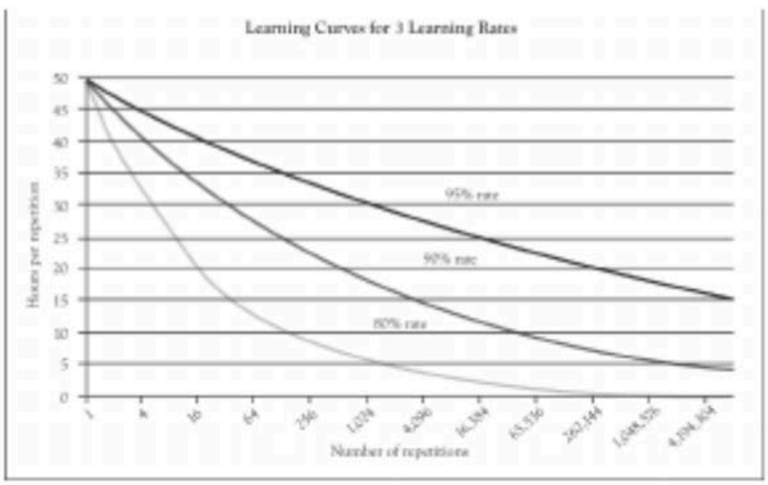


Figure 12. Example of Learning Rate Applied to 50-Hour Labor Task.
Source: Sower and Sower (2015).

According to the *FORSCOM Handbook for Cost and Price Analysis* (Forces Command DCS for Logistics, 2000), aeronautical engineers, when analyzing historical labor data regarding aircraft production, determined that there were specific rates of improvement for each successful completion of production when the successive production quantities doubled. Given this discovery, the “Number of Repetitions” column found in Figure 12 doubles for each row of new data. The graphic representation found in Figure 12 demonstrates the potential steepness of learning that an 80% rate could have on the task it is applied to. Choosing the correct rate is critical to an accurate cost estimate (Sower & Sower, 2015). Furthermore, “the learning curve, as originally conceived, analyzed labor hours over successive production units of a manufactured item, but the theory behind it has now been adapted to account for cost improvement across the organization” (ISPA, 2008, p. 2–7). Improvement, or learning curve theory is demonstrated using the following equation from the ISPA (2008, p. 2–7):

$$Y = AX^{b}$$

where:

Y	=	the cost of the Xth unit
A	=	(theoretical) first unit (T1) cost
X	=	unit number
b	=	the slope coefficient (defined as the Ln (slope) / Ln (2))

The ISPA handbook finds that

> there are two interpretations concerning how to apply this equation. In the unit interpretation, Y is the hours or cost of unit X only. In the cumulative average interpretation, Y is the average hours or cost of all units from 1 to X, inclusive.
>
> In parametric models, the learning curve is often used to analyze the direct cost of successively manufactured units. Direct cost equals the cost of both touch labor and direct materials in fixed dollars. This is sometimes called an improvement curve. The slope is calculated using hours or constant year dollars. (ISPA, 2008, p. 2–7)

In addition to understanding the improvement curve theory formula, applying the right technique is appropriate. The *GAO Cost Estimating and Assessment Guide* (2019) orients estimators to analyze production environments in order to dictate which formulation to use: unit formulation or cumulative average formulation. Choosing between the two is determined after analyzing the following factors:

1. Analogous systems
2. Industry standards
3. Historic experiences
4. Anticipated production environment

There is not a basic set of rules for estimators to follow when applying the type of formulation to a learning curve, but typically analogous systems use unit; when industry standards are used, it is best to use cumulative average; historic experiences will follow a common theme; and anticipated production environments may vary depending on the capability of production an organization is prepared to execute (Richey et al., 2009).

(1) Unit Curve Theory

According to *Cost Estimation Methods and Tools* (Mislick & Nussbaum, 2015), there are primarily two types of improvement curve theories. The first is unit curve theory. The basic understanding of unit curve theory is that as the production doubles, the cost to produce that amount decreases by a constant percentage. That percentage is the inverse of the learn rate applied. For example, if an 80% learning rate is applied, the cost of producing those units is reduced by 20%. Unit curve theory is typically used when production is well-defined, design is stable, and production lead times are typically longer (Mislick & Nussbaum, 2015).

(2) Cumulative Average Theory

For cumulative average theory, "Y" in the previous formula is the cumulative average cost of "X" units. Additionally, "X" becomes the cumulative number of units produced. In addition, an 80% learning rate generates a 20% decrease in *average* unit cost. This theory is typically applied when early production environments have the following characteristics:

- Use of “soft” or prototype tooling
- Inadequate supplier base established
- Early design changes
- Short lead times. (Mislick & Nussbaum, 2015, p. 206)

Given some or all of these production environment characteristics, the effect of averaging the unit costs helps reduce variation or “smooth” variations of unit costs (Mislick & Nussbaum, 2015).

b. Improvement Curve Theory Historically Acceptable Rates

Although there is not a set standard for rates, there are general guidelines for applying learning curve rates (slopes) depending on the characteristics of the industry and production environment. In *Cost Estimation Methods and Tools* (Mislick & Nussbaum, 2015) they offer the following*:*

> - If an operation is 75% manual and 25% automated, slopes are generally in the 80% vicinity
> - If an operation is 50% manual and 50% automated, slopes are generally about 85%
> - If an operation is 25% manual and 75% automated, slopes are generally about 90%.
> - Shipbuilding slopes are generally in the 80–85% range.
>
> The average slope for the aircraft industry is about 85%. But departments within an organization can vary greatly from that. Assuming repetitive operations within an industry, typical slopes may include:
>
> - Electrical: 75–85%
> - Electronics: 90–95%
> - Machining: 90–95%
> - Welding: 88–92%. (Mislick & Nussbaum, 2015, p. 184)

c. Production Rate

Production rates are an advancement of learning curve theory. As production increases, economies of scale set in, therefore reducing costs. The inverse is also true as breaks in production occur, or production rates decrease; costs tend to rise. The efficiency of production can be explained by adding a variable rate to the preexisting learning curve formula (Richey et al., 2009). This is demonstrated using the following equation:

$$Y = AX^{b}Q^{r}$$

where:

Y	=	the cost of the Xth unit
A	=	(Theoretical) first unit (T1) cost
X	=	unit number
b	=	the slope coefficient (defined as the Ln (slope) / Ln (2))
Q	=	production rate (quantity produced during the period or lot)
r	=	rate coefficient (Ln (production curve slope) / Ln (2))

The ISPA handbook recommends

> the equation is generally applicable only when there is substantial production at various rates. The production rate variable (Q^r) adjusts the first unit dollars (A) for various production rates during the life of the production effort. The equation also yields a rate-affected slope related to learning. (ISPA, 2008, p. 2–8)

d. JCM learning and production rates as a check on learning

By using the formulas outlined in this chapter, the data from Tables 4 and 5 and provide an example of the learning and production rate effects on JCM program cost.

Table 4. JCM Estimates Examined. Adapted from R. Mortlock (personal communication, November 14, 2019).

JCM Estimates Data Provided		
	JCP	**ICE**
Recurring Production Costs	$4,790,000,000	Unknown
T1	Unknown	Unknown
Learning Rate	93%	88%
Production Rate	83%	90%
Missiles to be Produced	48,613	48,613
JCP Data as variables		**Notes**
Y=	$4,790,000,000	Given in JCP
A=	Unknown	
X=	(1;48,613)	Given in JCP and ICE
b=	-0.1047	(Log(0.93)/Log(2))
Q=	(quantity of lot size)	Given in JCP. Ref. Table 5.
r=	-0.2688	(Log(0.83)/Log(2))
ICE Data as variables		**Notes**
Y=	Unknown	ICE(Y)= JCP(Y)*1.25
A=	Unknown	ICE(A)= JCP(A)*.84
X=	(1;48,613)	Given in JCP and ICE
b=	-0.1844	(Log(0.88)/Log(2))
Q=	(quantity of lot size)	Given in JCP. Ref. Table 5.
r=	-0.1520	(Log(0.90)/Log(2))

Table 5. JCM Procurement Profile. Adapted from R. Mortlock (personal communication, November 14, 2019).

	JCM Procurement profile										
Fiscal Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Procurement quantity	220	1,519	2,511	3,217	5,030	5,367	5,587	5,908	6,483	6,089	6,682

With the combination of both of the JCM cost estimates, the only variable left undefined for the JCP is the JCP T1. In an attempt to validate the data is accurate in the two reports the following is an example of using the production rate formula to solve for the JCP T1. To get to the JCP T1, the following computations were made using the summation variable γ.

$$\gamma = \sum_{1}^{Y} \sum_{1}^{N_Y} X^b \, Q^r$$

This equation solves for each individual unit cost when T1 is set to 1.

$$A = \frac{Y_T}{\gamma}$$

By using Excel and setting "A" equal to 1 and using all other defined variables of the production rate formula, each unit produced an individual fraction of the total T1 value. Summing each of the T1 parts or γ, then dividing the total recurring production costs by γ, the JCP is determined to have a T1 value of $2,657,412.

The list below displays some discrepancies within the two estimates using after solving for the JCP T1.

- Using the computed JCP T1 value of $2,657,412 and applying the appropriate learning and production rates, the ICE T1 would equal $2,648,497. This is calculated using the recurring production value of the JCP*1.25.

- The variance of T1s as stated in the ICE is 16%. JCP T1 is $2,657,412. ICE T1 is calculated using the assumed recurring production values for the ICE (JCP*1.25), at $2,648,497. This is less than 1% variance between the two estimates.

- The ICE inaccurately captured the procurement and total costs for the JCP. According to the JCP, procurement was $6.023b and total cost was $7.275b.

- According to the ICE, there was only a 5% difference in non-recurring procurement costs. Using a 25% difference in recurring production difference, no values calculated come close to the 16% T1 difference.

III. LITERATURE REVIEW

A. CASE STUDY METHODOLOGY

The application of teaching through case study has been applied for nearly a century by one of the most elite business schools in the country, Harvard Business School (HBS). According to *TopMBA.com*, roughly 30% of instruction time spent at top business schools is dedicated to learning through case study (TopMBA, 2017). Harvard, also being the global leader in case study development and sales, immerses its Master of Business Administration (MBA) students in nearly 500 cases throughout the two-year curriculum. “Simply put, we believe the case method is the best way to prepare students for the challenges of leadership” (Harvard Business School [HBS], n.d.).

1. Significance of Teaching Through Case Study

Case studies have been an integral part of academia for centuries, as they provide the student the opportunity to develop within the context of the study. This context offers the student the ability to become a stakeholder without the presence of loss or profit. “In terms of professional education, the key to effective preparation ultimately rests with the value employers and other end-users place on the focus, emphasis, and balance between the academic and practical in relationship to their own expectations for skills graduates must have to garner their interest” (Newman et al., 2019, p. 3).

Specific to the use of case study within higher education institutions (HEI) was the article “The Need for Case Studies to Illustrate Quality Practice: Teaching in Higher Education to Ensure Quality of Entry Level Professionals” (Newman et al., 2019). The article highlights the notion that organizations that pride themselves as reputable service providers or institutions are professional in nature, meaning that the organizations themselves follow ethical standards, are representative of expertise, and seek improvement of public perception through practice and self-regulation. The medical profession, business sector, and academia are thoroughbred examples of professional institutions that perform self-regulation and/or regulation while also always developing ways to increase capability (Newman et al., 2019).

According to two graduate-level educators, the central purpose of management education is to prepare students to operate effectively and responsibly within the unpredictable business environment. Students must be equipped with the knowledge of general business practices but also the increasingly difficult ability to socially perform within a team environment, and in most cases, lead (Prystupa & Luethi, 2017). While it is simple to issue institutional knowledge through lectures, lecturing alone will not produce the type of professional needed in the business environment. The use of case study appropriately forces students to independently absorb the material, analyze the case, and be prepared to debate, interact, or take direct action with others incumbent upon how the case study is proctored. The latter is the critical aspect of teaching through case study, which enriches both the students and teacher. The challenges students face from both their teachers and colleagues compel students to take ownership of their thoughts, opinions, and actions. These repetitions learned in the classroom environment are the outcomes that allow teaching through the case study method to thrive.

In 2008, the University of Oklahoma began seeking reform in the Department of Educational Administration, Curriculum, and Supervision for its Doctor of Education (EdD) degree. According to *Using JCEL case studies to meet ELCC standards*, there were three concerns that were driving the redesign of the program:

1. Writing skills of students

2. Faculty wanting some measure of what students had learned throughout the program because the general exam, over time, had morphed into a literature review or conceptualization of the students' dissertations

3. Driven by self-regulation, faculty expressing concerns with the National Council for Accreditation of Teacher Education (NCATE) requirements, specifically needing a way to capture that students were capable of demonstrating knowledge across specific domains. (Bass et al., 2011)

What the University of Oklahoma faculty found was a single solution that addressed all three concerns—teaching through case study. Given that their profession had developed, over time, a database of cases from which to teach—the *Journal of Cases in Educational Leadership* (JCEL)—faculty members now had a way to address their concerns. They were able to sift through the cases available in JCEL and utilize ones that brought dilemma and individual inquiry. Using case studies that students could relate to meant greater learning from each case study as well. Most notable to any profession was the following finding:

> Case analysis goes beneath the surface of the details of the cases to become a vehicle for self-examination and self-awareness. Self-knowledge is important to teacher leaders and administrators because of the diverse pool of constituents with whom they work: that is, central administration, building-level leadership teams, teachers, students, community networks, and parents. As students discuss cases in groups, their approach to technical or ethical dilemmas becomes apparent to their classmates and to themselves. As students work in groups, they learn their own biases as they discover that their opinion of how a case should be handled is different from those of their classmates. They are able to see that their personal approach to case analysis is influenced by their backgrounds and prior experiences. Students then move to think critically as they work through their differences with colleagues. (Bass et al., 2011, p. 11)

2. Writing a Case Study

While HBS primarily started teaching through case study in the early 1920s, other disciplines like law and medicine used case study as a central teaching mechanism even before that. Arguably equally critical to the application of case study to enrich learning outcomes is the practice of properly writing a case study. According to Starostka and Kurzyk (2017), an effective case study has a unique format and structure that is coupled with teaching instructions. From there, the case must include learning objectives. Having these key parts work in unison becomes the foundation for a well-written case study. As a method to achieve a well written case study, Starostka and Kurzyk offer a process by which one should develop a case study. The process can be seen in Figure 13.

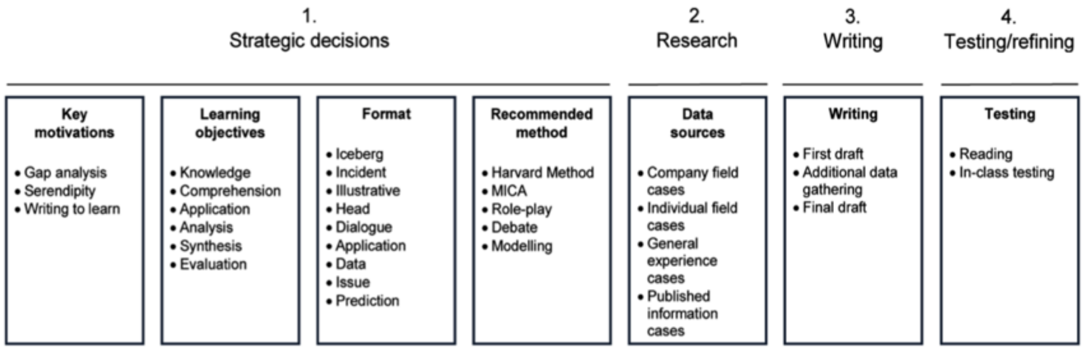


Figure 13. Four Stages of Case Study Development. Source: Starostka and Kurzyk (2017).

Anna Pikos (2017), in *Writing a Case Study: Research Design*, focused more on Steps 2 through 4 as outlined in Figure 13. Her findings suggested there is more of an abstract approach to developing a case study after its purpose has been clearly articulated and outlined. The strategic decisions outlined in Step 1 of Figure 13 show a methodical and deliberate approach to case study development, while Pikos suggested that case study development must be driven by data which the writer can collect. The approach of the writer may vary, but the data and subsequent case are dependent on thorough and exhaustive data collection. The more time the writer spends on research, the more enriched the case study becomes (Pikos, 2017).

B. WHY COST ESTIMATES MATTER

As previously mentioned, there are three main reasons why cost estimates are used within the DOD. According to Mislick and Nussbaum (2015), they are the following:

> *Long-term planning:* Long-term planning is part of strategic planning. Cost estimating fills the critical role of providing affordability analyses. It is true in all organizations—both government and nongovernment—that strategic changes are made only over the course of multiple years and it is necessary to know whether the costs associated with the change are "affordable." (Note: there are many ways to define affordable!) It is the cost estimating community that provides these initial cost estimates, and then it is others who decide where these estimates can be "afforded." Nevertheless, it is the cost estimating profession that provides the estimates of the resources necessary to embark upon and pursue these strategic changes.

> *Budgeting*: As an intrinsic part of building and refining budgets, cost estimating supports a series of activities that are aligned with the budgeting process. These activities include developing initial cost estimates for budget preparation, justifying cost estimates, and amending the estimates in the light of changing/changed circumstances.
>
> *Choosing among alternatives*: In support of decision-makers who must explore options and choose among alternatives, cost estimating supports the process by providing cost estimates and comparisons among the costs of alternative options for achieving a particular goal. It is applied to choosing among options in many walks of life. (Mislick & Nussbaum, 2015, p. 15)

1. DOD Develops CE Enterprise

Similar to the JCM program birth, the CAPE as it is known today (formerly known as CAIG), was the defense department’s response to congressional and constituent concerns about mismanagement of taxpayer dollars. According to Donald Srull (1998) in *The Cost Analysis Improvement Group: A History*, these congressional concerns were part of a larger, darker concern that the American people and their politicians recognized within the wake of the Vietnam War. In 1969, Congress mandated that the DOD publish system acquisition reports (SAR) in order to start an accountability process for the DOD and its flailing acquisition management network (Srull, 1998).

These reports, acquisition activities, and all matters within the DOD were further complicated by the ongoing war in Vietnam. The PPBE process had arrived a few short years before the start of the Vietnam conflict, and the DOD was still playing catch-up to its revolutionary budget process (Srull, 1998). To aid the Secretary of Defense, a counsel was developed, which similarly still exists today, to aid with decision-making regarding acquisition. These assistant secretaries of defense (ASDs include a comptroller, installations and logistics, and systems analysis (SA). Despite this counsel’s charge, by 1971, further cost and schedule overages plagued the DOD.

According to Srull (1998), the environment had shifted beneath the DOD in a matter of years, and by December 1971, the CAIG was established to assist the DOD with estimating costs early and often within the acquisition life cycle. The birth of the CAIG started within the SA office when it began comparing initial cost estimates with actual program costs in order to better understand the cost overages that had continued to mar the DOD. The cost comparisons were drastically different. There were many reasons for this. First, the nation had been at constant war for decades, with only intermittent gaps between conflicts, leaving little time to improve existing practices and gain efficiencies. Second, as cost estimating became relevant to the DOD, there were little to no data available to the estimators because most of the technology being developed lacked an analogous program or had only historical costs for comparison. Third, many of the DOD's programs were developed in an environment where cost was not a driving function, as procurement focused on "the newest and most advanced weapons at any cost" (Srull, 1998, p. 8).

2. Application of CEs

While acknowledging the main reasons to perform a cost estimate, the application of cost estimates varies based on the user. Often, cost estimates receive unfettered recognition when a figure or set of figures (estimates) are used to disparage the DOD for cost and schedule overruns. This typically comes in the fashion of a GAO report or a consulting firm's release of a summary of findings regarding cost growths for DOD programs. In any case, almost all materials found for this literature review were lacking the application of the CEs in the manner for which they were intended. Presumably, this is in large part because the nature in which cost estimates are developed leave tangible numbers to reference regardless of time. Numbers, especially dollar amounts in the billions, cast enormous shadows that the DOD must operate within when it fails to deliver.

An example of the use of cost estimates to report on DOD effectiveness is Lineberger's (2016) *Program Management in Aerospace and Defense: Still Late and Over Budget*. As a collective, the report provides a number of well-researched figures that show a positive outlook for defense acquisition, but it also highlights where trouble within the DOD acquisition environment may still loom. Using previous cost estimates to establish projected costs, the report finds that "total cost growth of today's MDAP [Major Defense Acquisition Program] portfolio over the original baseline estimates is 48.3 percent and an average delay of 29.5 months. In dollar terms, the combined cost overrun for all programs in 2015 was US$468 billion, up from US$295 billion from a similar study eight years ago"

(Lineberger, 2016, p. 8). Figure 14 shows how MDAP programs have fared in comparison to their baselines.

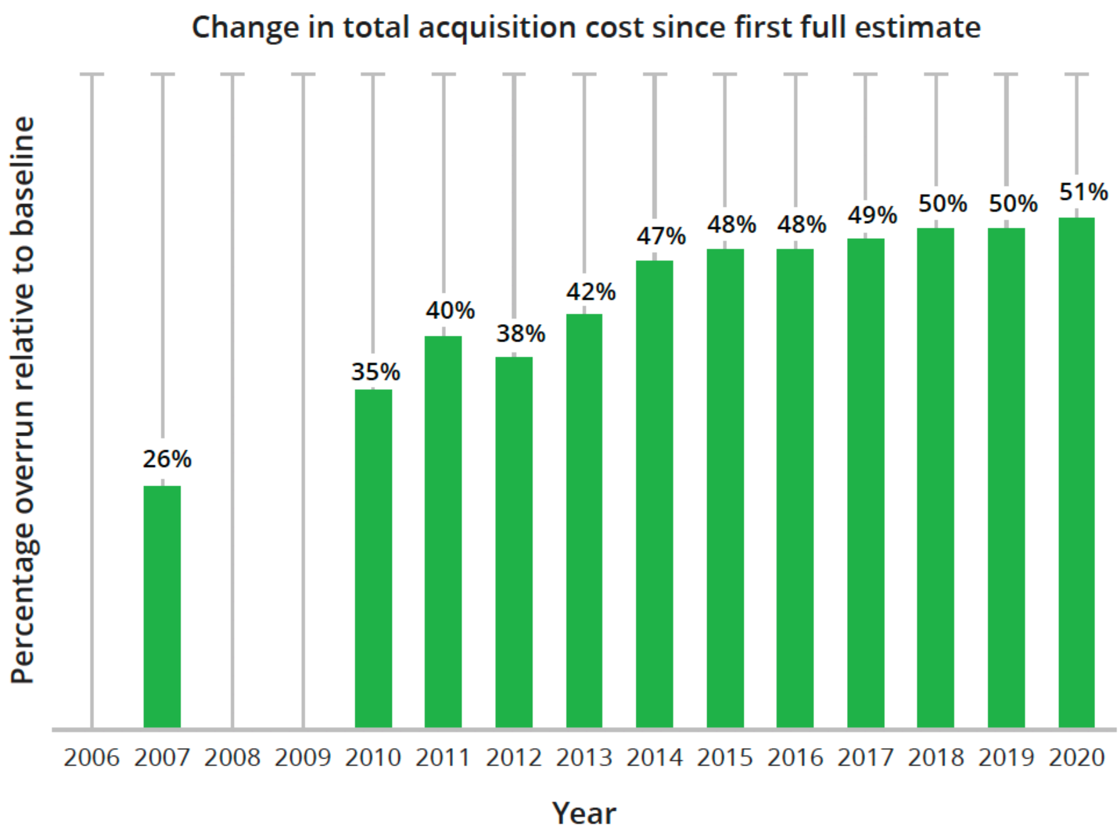


Figure 14. Current Cost Overrun since Original Estimate. Source: Lineberger (2016).

Beyond the analysis of cost overrun for MDAP programs in Lineberger's (2016) report is a table of findings that compares cost estimates with a current cost and its cost +/- over the course of five years. Figure 15 is particularly helpful in understanding how CEs can drive a budget or appropriation for both the DOD and Congress.

Program	Current total acquisition cost	Cost estimate T-5	5 year change	5 year change (%)	Reasons for cost increase / decrease
Evolved Expendable Launch Vehicle	$60,497	$18,643	$41,854	224.5%	Causes for this cost growth include extension of the program life-cycle from 2020 to 2030, procurement of 60 additional launch vehicles, unstable nature of the demand for launch services. Also, according to DoD officials, the inefficient buying practice of purchasing one vehicle at a time also contributed to the increase in costs.
F-35 Joint Strike Fighter	$339,997	$308,807	$31,190	10.1%	A restructuring was initiated in early 2010 when the program's unit cost estimates exceeded critical thresholds established by statute. DoD commenced efforts to significantly restructure the program and establish a new acquisition program baseline. These restructuring efforts continued through 2011 and into 2012, during which time the department increased the program's cost estimates, extended its testing and delivery schedules, and reduced near-term aircraft procurement quantities.
DDG 51 *Arleigh Burke* class Guided Missile Destroyer	$115,169	$102,738	$12,431	12.1%	Substantially modify the design, which would incorporate the new Air and Missile Defense Radar (AMDR), now under development, which will be larger and more capable than the radar on current DDG 51 destroyers. With those changes and associated increases in the ships' displacement, the average cost per ship over the entire production run would be $1.9 billion in 2015 dollars, or about 15 percent more than the Navy's estimate of $1.7 billion.
Warfighter Information Network-Tactical Increment 2	$10,433	$5,165	$5,268	102.0%	Changes in the relative mix of items being procured include a higher percentage of more expensive items. Also, the WIN-T Increment 2 procurement schedule was extended by 10 years. According to program officials, future unit cost growth remains an ongoing concern and the program could be at risk of an additional unit cost breach if there are significant quantity changes in the future.
Handheld, Manpack, and Small Form Fit Radios	$9,130	$5,211	$3,919	75.2%	Issues faced in the testing phases, where the Manpack did not meet reliability requirements twice, leading to schedule delays and cost overruns. However, redesigning efforts have been able to resolve these problems.

Amounts are U.S. 2016 dollars in millions.

Figure 15. Defense Programs with Major Cost Variations. Source: Lineberger (2016).

The benefit of this figure allows industry, Congress, and the DOD to see where and why cost overruns occurred. Given that CEs offer, at a given time, a sound and accurate estimate, there is utility in analyzing how far a program slips from that point of deviation. As the DOD collects more data, like the SA office did early in the 1970s, there is the likelihood that cost estimates will increase in accuracy.

IV. JOINT COMMON MISSILE CASE STUDY

A. SITUATION

The Army has selected you as an assistant program manager (APM) for the JCM program located at Redstone Arsenal, AL, within PEO TM. As required by both acquisition branch and human resources command, you reach out to the incumbent APM at the JCM program. You are excited to get caught up to speed on the program, and although the outgoing APM is constantly on temporary duty (TDY), she does respond promptly through email when connected. She recommends taking a deep dive into the JCM acquisition strategy to understand the program upon arrival, as well as reviewing all materials related to cost estimating, specifically learning curve theory and production rates. The variance between the ICE and the JCP are concerning to the leadership at PO JCM as they must discuss the differences with the MDA at MS B. Your arrival to JCM will come just prior to the DAE's DAB to facilitate JCM approval to enter into EMD post-MS B review. Program affordability will be the theme of discussion. Figure 16 represents the JCM design at this time.

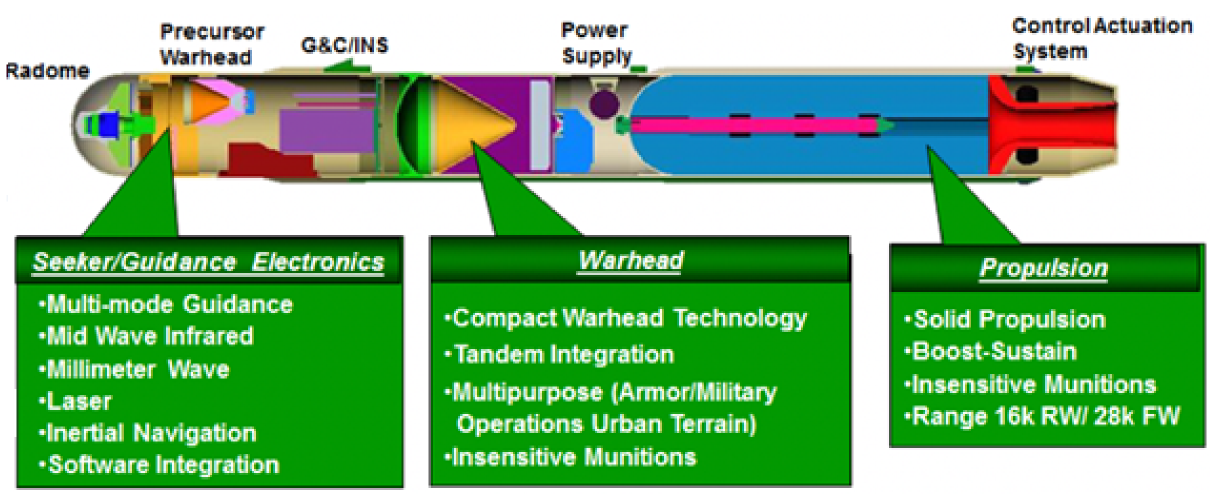


Figure 16. Notional JCM Design. Source: R. Mortlock (personal communication, January 9, 2020).

1. Program Background

The JCM program's path is unique, but the facts for where the program started through its current decision point are within the strategy document. The program is a joint ACAT ID program and the first-ever to utilize the JCIDS process. It is also an international program with one of the United States' closest allies, the United Kingdom. The development of the JCM capitalizes on existing S&T contracts executed by PEO TM that paid contractors to improve current missile technologies through R&D. The JCM program is seeking to merge multiple missile programs and capabilities into one modular system, thus improving capability while reducing logistical burdens within the DOD. The preexisting missile contracts were critical to enabling JCM to traverse the acquisition framework from capability gap in 1999 to hopefully an initial materiel solution by 2005, and an initial operational capability (IOC) by 2009 (R. Mortlock, personal communication, November 14, 2019). The program is facing MS B review, telling you that the program has completed its TMRR phase and is postured to start the EMD phase upon approval from the MDA (OUSD[A&S], 2020).

To this point, the JCM has technology that is independently rated at technology readiness level (TRL) 6 and above. In order to reduce the risk of combining multiple independent technologies into one system, the program intends to be developed incrementally. According to *The Joint Common Missile Project: Program Management Lessons Learned,* JCM PO also mitigated risk by focusing on modeling and simulation (M&S) during TMRR. In the request for proposal released in 2003, the proposal required contractors to include integrated flight simulation (IFS) as a driver to reduce risk later in the program's life cycle (Mortlock, 2005).

According to the acquisition strategy, JCM PO seeks to reduce risk by initiating EMD with multiple development efforts for critical technologies before beginning missile production. You remember from your initial acquisition training that competitive prototyping begins sometime after MS A unless waived by the MDA. In the JCM acquisition strategy, you only read how each contractor tested their specific technologies through prototypes and simulation, but the overall program did not have an all-inclusive prototype before arriving at MS B (OUSD[A&S], 2020).

2. Assignment

A day after your arrival to JCM PO, you receive the DAB slideshow, the JCP, and the ICE from the outgoing APM. You also receive your first official assignment as an acquisition officer, courtesy of your new boss, the JCM PM. You must review all documents and be prepared to discuss with the JCM PM two days prior to the DAB (which takes place this Friday). Since you initiated fact-finding and cost-estimating background information prior to your arrival to PEO TM, you have a head start before feedback is required. Your analysis must review the DAB slide presentation to establish the JCM PO standpoint, concerns, and positions heading into EMD. You must also review the CEs to potentially identify any additional risks or assumptions that the PO must include in the DAB. Due to the sensitivity of the DAB and its impending execution, bring any major concerns or recommendations to JCM PM immediately to reconcile.

B. DISCUSSION QUESTIONS

<u>Set 1:</u>

1. What are some basic facts as it relates to the JCM program after reading the acquisition strategy report?

2. Who are the primary stakeholders for the JCM program, and why?

3. What is cost estimating? Why is it done so frequently during a program's life cycle?

4. What are the primary methods of cost estimating? Explain in your own words what they are and when they might be used.

5. What is improvement curve theory and the associated production rate theory? What are their main differences?

<u>Set 2:</u>

1. The JCP reconciled differences between the program office estimate (POE) and the component cost analysis (CCA), performed by service cost estimate

organizations. For RDT&E costs, what was the primary cost estimating technique used by the POE? For the CCA?

2. Within the JCP for procurement costs, what is the largest cost element and why?

3. What cost estimating methodologies were used for recurring production for the POE and CCA?

4. What cost estimating methodologies were used for fielding costs for the POE and CCA?

5. Describe the primary differences between the JCP and the CAIG ICE?

6. With respect to recurring production, assumptions must be made about what primary drivers for the cost estimates?

7. Using the provided Excel document, give the T1s for the JCP and the ICE.

8. How can the T1, or theoretical first unit, for the CAIG ICE be lower than the T1 for the JCP, but the total cost estimate in CAIG ICE for recurring production be higher than in the JCP?

9. For recurring production, what does the CAIG ICE place more importance on: learning or production?

10. What, if any, are the risks associated with the JCP in terms of affordability, given the comparison between the JCP and the ICE?

11. What, if any, are the risks associated with the ICE in terms of affordability, given the comparison between the JCP and the ICE?

12. What recommendations do you make to PM regarding JCM affordability? Why?

C. JCM PROGRAM MATERIALS FOR ANALYSIS

The following sections are required to complete your review but are not all-inclusive on the analysis required to make recommendations to the JCM PM in two days' time.

1. Joint Common Missile Joint Cost Position Summary

The JCM JCP is a compilation of multiple cost estimates refined by a CRBWG, which produced one final estimate, the JCP (R. Mortlock, personal communication, November 14, 2019). The service lead for JCM, the USA, developed a POE and a CCA based off original assumptions of procurement and source selection. Those figures are represented under POE and CCA. It is important to note that both these columns are representative of assumptions to produce 30,978 missiles for the USA and two contracted sources for seeker development. The program was determined to be unaffordable with those assumptions; therefore the program was reconfigured to produce 15,613 missiles for the USA and reduce the number of seeker sources to a single contracted source. The USN portion of the JCP was accepted by Naval Air Systems Command (NAVAIR) and Naval Cost Analysis Division (NCAD). The final JCP position compiles a combination of assumptions between the USA cost estimates and the exact figures provided by the USN cost estimate (R. Mortlock, personal communication, November 14, 2019).

The following assumptions are factored into all POE and CCA figures, thus influencing the JCP.

- Cost presented in Fiscal Year (FY) 2004 constant dollars
- Used January 2004 inflation indices
- Unique Navy requirements estimated by NAVAIR
- Scope of estimate is for Increment 1
- Phase 1: Risk Reduction (12-14 Months); Phase 2: System Demonstration (36 Months)
- RDT&E: Cost plus incentive fee-type contract
- LRIP: FY2008-FY2009 (fixed price incentive-type contract)
- Long-lead required for all LRIP procurements beginning in FY2007
- Full-rate production starts in FY2010 (fixed price contract)
- Army platform is the Apache (AH-64D) with M299 launcher; software only changes to platform
- Navy platforms include the Cobra (AH-1Z), F/A-18, and MH-60; software and hardware changes to the platforms

- No additional manpower required for the M299 launcher maintenance
- Shared learning based on missile procurement of Army 15,613 and Navy 33,000
- Rate curve is applied to procurement
- Missile is a certified round; will not require field maintenance
- Software maintained by AMRDEC Software Engineering Directorate (SED; Level 4 certified in capability maturity model)
- Stockpile reliability testing will be conducted
- Software upgrades in FY2013, FY2018, FY2023
- Applies a 10% reduction to LRIP 1 & 2 to compensate for competition during source selection
- Counter Active Protection System (CAPS) placed on 10% of rounds (R. Mortlock, personal communication, November 14, 2019)

The four main areas to highlight within the JCP are RDT&E, procurement, operations and maintenance, and the JCM PO's risk mitigation efforts. Tables 6–8 break down the various estimates and their associated costs based on the methods used by each.

a. JCP Research, Development, Test, and Evaluation

Table 6. JCP RDT&E cost elements. Source: R. Mortlock (personal communication, November 14, 2019).

	COST ELEMENT	Army Estimate		Reconciled Estimate		
		POE	CCA	Army	Navy	JCP
1.0	**RDT & E**	**555**	**786**	**552**	**418**	**970**
1.01	Development Engineering	195	228	183	93	276
1.011	Hardware Dev Eng	128	105	125	23	148
1.012	Software Dev Eng	67	123	58	70	128
1.02	Producibility Eng & Planning	9	19	6	3	9
1.03	Development Tooling	20	35	28	20	48
1.04	Prototype Manufacturing	84	136	91	85	176
1.0	System Eng/Program Management	164	257	169	74	243
1.051	Government SE/PM	138	91	91	66	166
1.052	Contractor SE/PM	26	166	78	8	86
1.06	System Test & Evaluation	71	93	66	125	191
1.07	Training	6	6	4	8	12
1.08	Data	2	8	2	0	2
1.09	Support Equipment	4	4	3	8	11
1.11	Other RDT&E	44	0	0	0	0

The POE and CCA reflect the original assumptions for multiple sources and quantities. JCP position reflects proper source amount and reduced amount for USA JCM missiles.

This table uses BY2004 dollars in millions.

The JCP also articulates that much of the variance between the POE and CCA are due to the methods of cost estimating applied to the JCM program. The POE relied heavily on the analogy method, while the CCA utilized cost estimating relationships (parametric) for the majority of their cost elements depicted in Table 4. According to the JCP, the CRBWG analyzed each of the estimates to determine the most suitable estimate for the JCP. In most cases, it resulted in the JCP adopting the figures of the POE, and not the CCA, with caveats. The CRBWG identified that certain areas of both estimates failed to account for the multiple sensors integrated into a single seeker, creating risk, and therefore producing figures greater than typically found in the POE figures. The minor adjustments are annotated throughout the JCP.

According to the JCP, another major difference between the POE and CCA estimates for RDT&E was captured in the theoretical firsts and how they were applied to prototype manufacturing. The POE used analogous comparisons to the Javelin missile and its components and subcomponents. The CCA again utilized CERs to develop its cost estimates. The recurring theme between the two estimates is the utilization of analogy method for the POE and the CCA using parametric with some analogy and expert opinion where certain data was not available (R. Mortlock, personal communication, November 14, 2019).

b. JCP Procurement

The next cost component to be analyzed is procurement costs. Within the JCP, this cost pool accounts for 83% of the total cost to the program. The cost drivers for procurement are recurring production costs, SE program management, fielding, and other procurement (software maintenance). Table 5 shows the breakout of the major lines of cost that produce the total procurement cost.

Table 7. JCP Procurement Cost Elements. Source: R. Mortlock (personal communication, November 14, 2019).

	COST ELEMENT	Army Estimate		Reconciled Estimate		
		POE	CCA	Army	Navy	JCP
2.0	**PROCUREMENT**	**3758**	**3941**	**2162**	**3861**	**6023**
2.01	Non-Recurring Prod Sys Mngmt	65	49	35	42	77
2.02	Recurring Production	3210	3086	1607	3183	4790
2.03	Engineering Changes	18	0	9	19	28
2.04	System Eng/Program Management	243	479	274	364	638
2.041	Government SE/PM	145	143	145	72	217
2.042	Contractor SE/PM	98	336	129	292	421
2.05	System Test & Evaluation	48	21	34	30	64
2.06	Training	130	130	128	0	128
2.07	Data	16	16	9	14	23
2.08	Support Equipment	2	2	2	0	2
2.10	Fielding	26	50	30	0	30
2.14	Other Procurement	0	110	33	210	243

This table uses BY2004 dollars in millions.

The most important cost driver to procurement is recurring production, shown in Table 5 as line item 2.02 and is valued at a final position of just over $4 billion for the JCM program. It is within recurring production and additional procurement costs that the learning curves and production rates greatly impact the total cost of the program. According to the CRBWG, the POE estimate relied heavily on analogy costs to derive T1s for the components and subcomponents of recurring production based on comparisons to the Javelin missile program. Again, the CCA relied more heavily on CERs and analogies to similar systems.

c. JCP Operations and Maintenance

Although most typical hardware programs generate the majority of their costs during operations and maintenance (O&M), the JCM program's major costs are a product of production. As stated earlier, there are some key assumptions that drive down cost during O&M. The most important assumption derived from the list above is that the JCM round, once fielded, will not require field maintenance. Another important assumption is that the software maintenance needed to be performed is on the systems operating the munition and not the munition itself. Due to these assumptions, the final JCP cost element for O&M equates to just 3% of the total program cost. Table 6 shows the final breakdown of cost elements for O&M according to the JCP (R. Mortlock, personal communication, November 14, 2019).

Table 8. JCP Operations and Maintenance Cost Elements. Source: R. Mortlock (personal communication, November 14, 2019).

	COST ELEMENT	Army Estimate		Reconciled Estimate		
		POE	CCA	Army	Navy	JCP
5.0	Operations & Maintenance	147	0	179	88	267
5.01	Field Main. Civ. Labor	0	0	29	0	29
5.02	System Specific Base Ops	0	0	0	0	0
5.03	Replenishment - Depot Level Reps	2	0	2	0	2
5.06	End Item Supply & Maintenance	78	0	50	21	71
5.07	Transportation	13	0	14	5	19
5.08	Software	26	71	39	0	39
5.09	System Test & Evaluation	15	0	15	23	38
5.10	System Eng/Program Management	26	0	28	23	51
5.11	Training	3	0	3	0	3
5.12	Other	0	0	0	16	16

This table uses BY2004 dollars in millions.

According to the JCP, the CRBWG determined that the spare parts, repair parts, and software drove the cost elements for O&M. Of note, only the CCA followed the assumptions outlined at the beginning of the JCP by only recognizing software maintenance for their estimate. Additionally, the USN position, and the one adopted by the JCP, had zero dollars allocated for software maintenance. The JCP utilized bottom-up and analogy methods to determine their final cost position. They used the Hellfire and Longbow Hellfire missiles to establish failure rates and repair rates base on missile manufacturing.

d. JCP Risk Mitigation and Affordability

According to the CRBWG, it was determined that the JCM program risk rating was low to moderate. Previous risks to the JCM were reliability and producibility, but since the establishment of the JCM PO, the efforts in engineering have reduced these risks. The JCP also states that the technical risks are migrating to low as well. Table 9 depicts the risk dollars used to mitigate the identified risks from earlier in the program (R. Mortlock, personal communication, November 14, 2019).

Table 9. JCP Risk Dollar Allocations. Source: R. Mortlock (personal communication, November 14, 2019).

Item	Risk Rating		Risk $
Propulsion	MOD	Additional Testing added to program	1.6
Warhead/Fuze	MOD	Risk Distribution	1.9
Software Software	MOD	Accounted for with SW Growth	24.0
Radome	MOD	Two Radome Designs thru CDR	0.6
Missile Integration	MOD	Risk Distribution (High Risk)	42.0
Total Risk Dollars			70.1

Risk Phasing						
FY04	FY05	FY06	FY07	FY08	FY09	Total
5.0	9.9	21.1	20.2	8.4	5.4	70.0

Risk analysis is based on the Joint Risk Assessment conducted by the PM and ATEC in Sep 03.

This table uses BY2004 dollars in millions.

As it relates to program affordability, the JCP offers a promising outlook to the JCM program. Table 10 illustrates how well the program has estimated costs to maintain affordability. Overall, the program has a negative delta just twice in the next seven years of budgeted dollars. The greatest concern being $2 million in FY2008. The JCM PO's plan to address both negative deltas is found within the table (R. Mortlock, personal communication, November 14, 2019).

Table 10. JCP Affordability Assessment. Source: R. Mortlock (personal communication, November 14, 2019).

RDT&E (TY$M)								
RDTE ($M)	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY06-11
Joint Cost Position	152.5	146.4	83.0	71.1	29.3	0.0	0.0	329.8
Funding (BF3.0)	152.4	146.9	84.0	67.1	57.1	0.0	0.0	355.0
Delta	**(0.1)**	**0.5**	**0.9**	**(4.0)**	**27.8**	**0.0**	**0.0**	**25.2**
Procurement								
Procurement ($M)	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY06-11
Joint Cost Position			6.1	69.7	129.5	196.1	199.5	600.9
Funding (BF3.0)			6.2	71.7	102.8	196.1	199.5	576.3
Delta	**0.0**	**0.0**	**0.1**	**2.0**	**(26.7)**	**0.0**	**0.0**	**(24.6)**
Total								
Total ($M)	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY06-11
Joint Cost Position	152.5	146.4	89.1	140.8	158.8	196.1	199.5	930.7
Funding (BF3.0)	152.4	146.9	90.2	138.8	159.9	196.1	199.5	931.3
Delta	**(0.1)**	**0.5**	**1.1**	**(2.0)**	**1.1**	**0.0**	**0.0**	**0.6**

- This plan procures 15,613 missiles during FY08-18 utilizing current JCM funding.
- FY08 shortfall ($2.0M) will be funded in POM FY06-11.
- Reprogram FY09 RDTE surplus to fully fund FY09 procurement requirement.

2. CAIG ICE for JCM Program Summary

The independent cost estimate performed by CAIG (now CAPE) has a different story to tell as it describes JCM affordability, but the net difference between the two CEs is just 25% as shown in Table 11. The primary differences between the two cost estimates is the development effort needed for the JCM and the recurring production costs for the missile. According to the ICE, both O&M and military personnel cost elements were well within estimating margins and therefore, were not captured in the summary report.

Table 11. JCM JCP and CAIG ICE Life-Cycle Cost Comparison. Adapted from R. Mortlock (personal communication, November 14, 2019).

Cost Element		Cost Estimate Source		Dollar Difference	% Increase of CAIG CE	% of Cost Increases
		JCP	CAIG			
1.0	RDT&E	970	1,350	380	39%	21%
2.0	Procurement	6,023	7,490	1,467	24%	79%
4.0	Military Personnel	15	20	5	33%	0%
5.0	Operations and Maintenance	267	270	3	1%	0%
	Total Life Cycle Costs	7,275	9,130	1,840	25%	

This table uses BY 2004 dollars in millions.

a. ICE Research, Development, Test, and Evaluation Effort Duration

According to CAIG's ICE, the JCP projected a 48-month RDT&E. The base assumption for this duration was that the type of technology that was being integrated into the JCM missile was mature technology. According to the services, the technologies were nondevelopmental and consequently did not require longer development efforts. CAIG disagreed with this assumption, using a review of historical missile programs that incorporated multimode seeker technologies. In doing so, the CAIG estimate determined a developmental effort lasting 26 months longer than was required for the JCM program. This increase made the total time the JCM program would execute RDT&E increase to 74 months. The increase to 74 months is the primary driver for the 39% increase of budgeted dollars for RDT&E in the ICE (R. Mortlock, personal communication, November 14, 2019).

The CAIG also cautioned that the DOD had a very poor track record of developing dual-mode seeker technologies into missiles, let alone multimode. The data CAIG references portrays programs having trouble due to data processing of multiple seekers and the ability for the missile to track properly while operating two seekers simultaneously. Although the JCM was planned to have three seeker technologies, it would only actively operate two at a time, reducing some complexity (R. Mortlock, personal communication, 2019). Although the CAIG settled on 74 months for development effort duration, the final thought offered by the ICE was the JCM program could easily incur a 147-month development effort given the complexity of the JCM and its requirements (R. Mortlock, personal communication, November 14, 2019).

b. ICE Procurement Costs

While the JCP failed to articulate the T1s or the learning and production rates, CAIG's ICE offered such information. According to the ICE, the main difference between the JCP and the ICE rests with the assumptions of these rates and how they were applied. According to the ICE, the T1 used for the CAIG CE is actually 16% lower than the T1 used in the JCP despite the overall increase the CAIG predicted for procurement costs.

In order to compare the difference between the two estimates, the CAIG offered its method of application for the learning and production rates. The rate of learning applied by CAIG was 88% and a production rate effect of 90%. The CAIG developed these rates through regression analysis of 12 previous missile production programs. As the CAIG compared its rates to the JCP, it was determined that the JCP used T1s and cost progress curves for each component and subcomponent of production. In order to compare the two figures effectively, the ICE averaged the respective rates of the JCP to develop a 93% learning curve rate and an 83% production rate effect. According to the ICE, the 83% production rate effect is an aggressive rate but not considered unprecedented (R. Mortlock, personal communication, November 14, 2019).

To further contrast the CAIG and the JCP, the CAIG notes the procurement profile of the JCM program that is not typical for missile programs. According to the ICE, missile programs seek to achieve a "tooled rate" earlier in production, and then have quantities reduced thereafter. Shown in Table 12, the missile procurement profile exhibits a continual increase in production amounts, allowing the production rate effect to continue its cost reductions throughout the program.

Table 12. Procurement Quantities of JCM Missiles. Source: R. Mortlock (personal communication, November 14, 2019).

ITEM	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13	FY 14	FY 15	FY 16	FY 17	FY 18	Total
Missle												
ARMY	69	395	782	888	1030	1317	1537	1858	2433	2039	3265	15613
NAVY	151	1124	1729	2329	4000	4050	4050	4050	4050	4050	3417	33000
	220	1519	2511	3217	5030	5367	5587	5908	6483	6089	6682	48613

The only other increase in procurement costs found by the ICE was the requirement to include global positioning on all missiles, for both USA and USN at a cost of $7,000 per missile. In total, the combination of T1s, which is 16% greater in the JCP, the learning rate of 93%, and the highly aggressive 83% production rate effect, coupled with the missile procurement profile found in Table 12 account for a 40% swing in costs between the two CEs (R. Mortlock, personal communication, November 14, 2019).

c. ICE JCM Program Risks

CAIG's ICE of the JCM program also summarized how the developmental efforts and production rates may affect the JCM program in the future. For RDT&E, the CAIG discussed the impacts of the increase of development efforts against the current LRIP and secondary LRIP. Concern is also echoed that despite the program's use of S&M, the fact that the JCM has yet to fly a prototype at MS B is of concern. The plan to conduct developmental testing (DT) while advance procurement of LRIP missiles is being executed could greatly impact costs if production needs to be suspended while technical complications are remedied.

While the ICE did not outright object to the learning and production rates applied to the JCM program, it did provide context for how those rates could greatly impact affordability as future constraints arise. Beyond the challenges the program may face with procurement and its applied rates, the challenge becomes affordability if quantities of JCM are further reduced. The USA reduced its acquisition of JCM by virtually half to make the program affordable. If further reductions of quantities occur, the average procurement unit cost and program acquisition unit cost will increase dramatically.

3. DAB Summary

Figure 17 captures the slides most relevant to your analysis and will assist you in framing your recommendations.

Comparisons of Cost Estimates

RDTE	FY04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Total
PB05	107.6	235.2	264.2	146.2	104.5	82.1	0.0	0.0	939.8
PB05+POM0611 adds	107.1	235.3	272.6	196.8	157.7	46.4	0.0	0.0	1015.9
JCP	107.0	235.4	272.0	196.8	157.7	46.4	0.0	0.0	1015.3
ICE	37.0	147.4	264.0	305.2	276.2	207.1	131.9	72.3	1441.1
Delta $ (POM0611-JCP)	0.1	-0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.6
Delta $ (POM0611-ICE)	70.1	87.9	8.6	-108.4	-118.5	-160.7	-131.9	-72.3	-425.2

PROCUREMENT	FY04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Total
PB05	0.0	0.0	0.0	7.2	94.7	149.8	196.0	199.5	647.2
PB05+POM0611 adds	0.0	0.0	0.0	12.5	194.9	407.7	518.2	568.9	1702.2
JCP	0.0	0.0	0.0	12.4	194.8	407.7	518.4	568.9	1702.2
ICE	0.0	0.0	0.0	0.0	0.0	0.0	186.4	806.7	993.1
Delta $ (POM0611-JCP)	0.0	0.0	0.0	0.1	0.1	0.0	-0.2	0.0	0.0
Delta $ (POM0611-ICE)	0.0	0.0	0.0	12.5	194.9	407.7	331.8	-237.8	709.1

TOTAL FUNDING	FY04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	Total
PB05	107.6	235.2	264.2	153.4	199.2	231.9	196.0	199.5	1587.0
PB05+POM0611 adds	107.1	235.3	272.6	209.3	352.6	454.1	518.2	568.9	2718.1
JCP	107.0	235.4	272.0	209.2	352.5	454.1	518.4	568.9	2717.5
CAIG ICE	37.0	147.4	264.0	305.2	276.2	207.1	318.3	879.0	2434.2
Delta $ (POM0611-JCP)	0.1	-0.1	0.6	0.1	0.1	0.0	-0.2	0.0	0.6
Delta $ (POM0611-ICE)	70.1	87.9	8.6	-95.9	76.4	247.0	199.9	-310.1	283.9

Total Funding Covers Either JCP or ICE

Requested Program

- Execute SDD on the 4-year schedule
- Fund to the JCP
- Assess program during SDD – adjust as needed
  - IPR ~ 14 months after CA
    - Co-chaired by PEO-TM and PEO-W
    - Briefed to OIPT
  - DRR ~ 24 months after CA
    - Co-chaired by the PEO-TM and PEO-W
    - Briefed to OIPT
  - CPD JROC review and analysis (36-40 months after CA)

Best approach to achieving an FY09 IOC

JCM Estimate

Development Effort Duration Estimates

CAIG METHOD: Used Actuals of Non-Developmental Single Seeker Missile Programs Adjusted for Dual Mode Schedule Premium

Non Developmental Single Seeker Programs
Average MSII to LRIP Duration = 48.3 Months

- JSOW Unitary - Upgrade of JSOW with NDI IIR Seeker
- JASSM – Follow-on to TASSM; includes NDI IIR Seeker
- AIM-9X – 5th Generation IIR Seeker into Sidewinder Missile

Dual Mode Schedule Premium Factor = 1.53

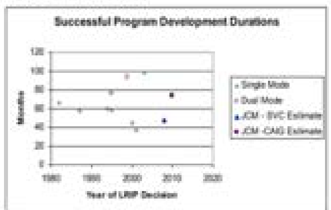
Average of Successful Dual Mode Programs	84.5 months
Average of Successful Single Mode Programs	55.1 Months

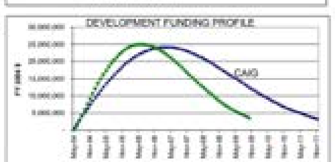
CAIG Estimate: Single Seeker NDI Effort (48.3) x Dual Mode Schedule Premium (1.53) = 74 months

MS B to LRIP Development Time (Months)

Army	*CAIG*	*Difference*
48	74	26

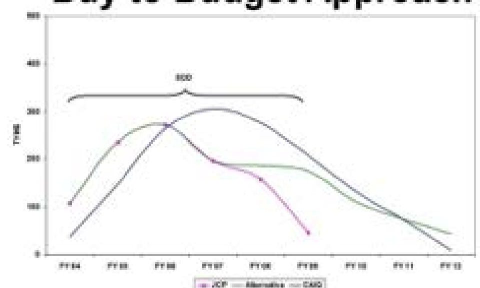
CAIG Method Accounts for NDI Benefits, JCM Maturity, and Maintains Independence From Service's Schedule Estimate





OSD CAIG

Buy to Budget Approach



•Program offered:

–48-month acquisition strategy provides opportunity to introduce capability sooner to mitigate declining inventory shortfalls (Navy Maverick depletion FY11) and address critical capability gaps

–Buy to budget approach converts procurement to RDT&E now consistent with CAIG schedule (funds can be converted back as necessary)

–Army/Navy must protect RDT&E $ beyond 48 month contract

–Unused RDT&E must be used to procure missiles

–The acquisition strategy has assessment points, with OIPT oversight, throughout SDD

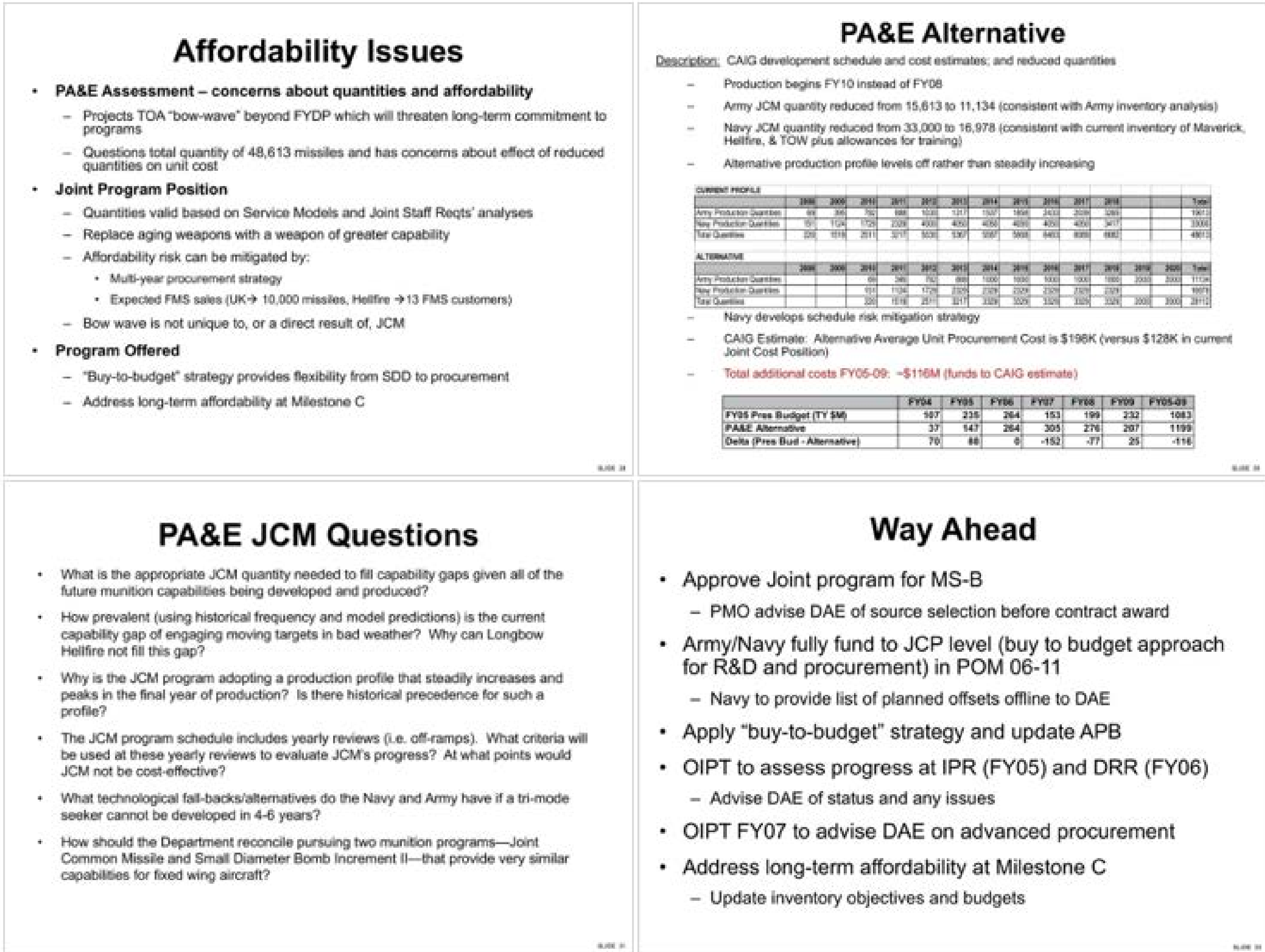


Figure 17. JCM DAB Slides for Analysis. Source: R. Mortlock (personal communication, January 9, 2020).

D. INSTRUCTOR’S MANUAL

Developing a case study is a cyclical process that is guided by many tools, and how those tools interact with the audience is critical in the improvement of learning outcomes and the case study itself. This project was developed with this in mind and therefore provides recommended teaching strategies, focusing on techniques and learning objectives. There are two methods of execution, and both vary given the complexity the instructor desires.

1. Teaching Methodology and Format

According to Starostka and Kurzyk (2017), both the format and method of case study are critical to achieving a meaningful case study execution. This case study was designed to be taught in just one three-hour iteration but can easily be adapted for a more in-depth review of cost estimates within the acquisition environment if desired. For those reasons, there are two different methods of recommended application, but both attempt to achieve the same learning objectives. The first is the most common method, the Harvard case method, and the second is the McAleer Interactive Case Analysis (MICA). Regardless of the methodology used to execute the case study, understanding the multiple CEs associated with the JCM program cannot be done in one three-hour sitting. Because of this, students are issued the instructions for the case study and the associated reading materials prior to the formal case study class. In addition, the discussion questions are divided into two parts. The first set of questions is intended to be distributed with the case study materials in advance. The second set of questions will be proctored by the instructor as he or she sees fit, in an attempt to guide students through all learning objectives while in the classroom environment (Starostka & Kurzyk, 2017).

a. Harvard Case Study Method of Execution

The first of the two possible methods of instruction for the JCM case study is the Harvard method. According to Starostka and Kurzyk (2017), the use of the Harvard method requires the instructor to be well-versed in the subject material and able to navigate the difficult dilemmas that may arise between students during their discussion of the questions which they answered prior to arriving in class. Additionally, student participation is also a limitation to this method, as the instructor must maintain student dialogue, keep focus, and prevent students from lack of preparation. This also may subject the professor to taking too active of a role in the discussion, rather than letting the discussions be largely executed by the students themselves (Starostka & Kurzyk, 2017).

b. McAleer Interactive Case Analysis (MICA) Method of Execution

Starostka and Kurzyk (2017) describe the MICA method as one that emphasizes written documentation and student roles, which differs from the Harvard method. The two primary reasons for using the MICA method are to attempt to eliminate the need for a highly skilled instructor (or one that is not comfortable with the material), to strengthen student interaction by requiring students to submit answers to questions ahead of time. A third advantage of this method is that it includes specific criteria for evaluation. (Desiraju & Gopinath, 2001).

For this method, the instructor provides all the discussion questions in advance and requires submission of the discussion questions electronically in order to collect answers prior to the formal case study. From there, the class affords roughly a third of the students to volunteer as the administrative team. These members collect the answers to the discussion questions and primarily focus on the "action steps" or recommendations students submit. The administrative team then prioritizes each recommendation, grouping them if similar, to then drive discussion in the formal portion of the class.

During the formal discussions, the students are called on to present their argument for why they arrived at a given recommendation, while the instructor can serve in a passive role and focus on grading student participation. One key reason the administrative team seeks to allow students to defend their recommendations is to ensure equal opportunity to participate. In the Harvard case method, it is possible that only a few students drive the discussions, while the MICA seeks to eliminate that (Desiraju & Gopinath, 2001).

2. JCM Case Study Learning Objectives

The following learning objectives were generated based on the outline discussed in Figure 12. These objectives attempt to ensure that students gain knowledge, comprehension, application, analysis, synthesis, and an evaluation as it relates to the impacts of cost estimates on decision-making.

- Demonstrated understanding of what cost estimates are; how they are applied in acquisitions; what the main methods of cost estimating are; and how to read cost estimates and understand the figures associated with each

- Shows understanding of where and how improvement curve and production rates can be applied properly

- Given proper data, T1s can be engineered to inform decisions

- Recommendations for decision-making are defensible based on ability to translate cost estimate data into risk assumptions and mitigations

According to Starostka and Kurzyk (2017), the format of the case study is vital to achieving the learning objectives. For this case study, it begins as an "iceberg" case, as students must use minimal knowledge of the program and cost estimating to answer the first set of discussion questions. This limited structure doesn't require students to make decisions but asks them to gather necessary information that may lead to a recommendation (Starostka & Kurzyk, 2017).

When formal classroom instruction begins, students have completed a fact-finding exercise of the JCM program and analyzed its associated cost estimates. Depending on the method of instruction, some or all of the discussion questions have been answered prior to convening. From there, the case study develops into an "illustrative" case where students deliberate over discussion questions in the classroom depending on the method chosen by the instructor. By the end of the case study, using proper teaching methods and formats, the learning objectives will be met.

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V. SUMMARY AND CONCLUSIONS

A. SUMMARY

This project was intended to develop my personal and professional understanding of the impacts of cost estimates, their assumptions, applications, and methods as I enter the acquisition workforce. Utilizing the JCM program, its various CEs, and their application within a PO gave me great insight to how programs rely on the figures they provide. The case study allows for participants to establish their own recommendation to the PM and the MDA if they were operating as an APM within JCM PO. Sharing these recommendations in a schoolhouse environment will certainly increase participants' understanding of CEs and their underlying assumptions as they relate to the decisions they influence. I am excited to offer my recommendation as insight to my personal learning objectives that I achieved by producing this project.

1. Author's Findings

Whether using either the ICE's estimate of the JCM program or the JCP's, the majority of the affordability concerns are within procurement for the JCM program. The major cost driver for procurement is recurring production. Using the JCP's rough figures, the recurring production cost is nearly 65% of the total program cost. The learning and production rates applied to the estimates has extreme weight in determining if the JCM program is indeed affordable. Ensuring the right rates are applied to the program is critical in deciding about whether the JCM can continue as designed.

As important as the cost estimates are to answering the affordability questions for any program, the two reports analyzed in this project seem to be disconnected and difficult to determine what information for which estimate is accurate and supportable as a senior decision-maker. After carefully researching and applying the proper mathematical formulas for learning and production rates, the ICE's cautionary concerns regarding the length of EMD are immediately concerning to program affordability but not something the program cannot overcome. From there, it is difficult to support the ICE's comparison of production and procurement costs due to the number of inaccurate figures published.

With the JCP however, there is a lack of data in the lengthy report. Critical to understanding the CE needed to include the learning and production rates due to their profound effect on the overall program cost. Without these figures, it somewhat hides the concern the program has as about affordability given the aggressive production rate and the procurement profile recommended. Those factors, coupled with the shortest possible EMD duration demonstrate that the program is already exceeding its costs and aggressive timelines and factors must be used in order to proceed with the JCM as originally designed.

2. Author's Recommendation to JCM PM

The JCM program is a high visibility program due to its JCIDS participation and the ACAT ID designation. The program's incorporation of international partnerships compounds the pressure the PO has to ensure the program's success. Despite the early achievement of using S&M as part of the ongoing contracts PEO TM used to jumpstart the JCM program, my first recommendation is to increase the duration of RDT&E found in the ICE to the maximum extent possible. The reason for this is due to the CAIG's use of historical data, which references multi-seeker complications on missile platforms. Ignoring these planning horizons is a critical failure of the program. Furthermore, assess the time it will take to produce the first prototype. Understanding the prototype project and its associated schedule and cost will allow the PM to determine which path of RDT&E is more accurate between the JCP and the ICE. This will also influence the time to DT and when advance procurement of Increment 1 LRIP can begin.

As previously, the ability for the program to develop a prototype does more than just influence schedule. Prototyping also allows for the cost estimator to perform the "step-down" function to help predict the T1 cost rather than use the methods found in the JCP or ICE (Richey et al., 2009). This then influences the largest portion of the JCM budget, procurement. With more accurate figures, the JCM program can better estimate future affordability. While using the T1 from the ICE and then applying it to the rates used in the JCP may show a substantial reduction in cost, it is more appropriate to use actuals as the program progresses. Additionally, the methodology to increase unit production throughout the life of the program is contingent on the ability of the contractor to increase the production rate every lot. As shown in Table 8, the program applied a production rate effect due to the increase in production amounts. Rate and quantity are not synonymous. This assumes that the contractor will increase the rate at which it produces JCM in order to achieve the rate effect of 83% for each production lot.

Depending on how well received the first two recommendations for the JCM program are, I would close with a final recommendation to the PM that more cost elements found within the JCP should assume the parametric method to improve its cost position rather than rely so heavily on analogy and assumptions of JCM program.

B. CONCLUSIONS

1. Cost Estimates and Their Assumptions

Because I am a future APM and hopefully PM within the acquisition environment, I appreciate that the use of CEs provides insight into the affordability of a program. The challenge, however, is to accurately align assumptions with best practice and the information present within the program's environment. For JCM, the PO firmly believed that the independent technologies were mature enough to be integrated into one system with minimal issue. They recommended the 48-month RDT&E at the DAB for MDA approval despite historic data. The PO also supported certain methods within the JCP that could have been improved upon. There are a number of instances where the parametric method would improve the JCP. Knowing the difference between the methods can help POs better understand the figures present in the CEs produced.

I have yet to work within an acquisition program, but the disregard of historical data to promote a supported timeline to budgeted dollars is concerning. When evaluating the CEs against budgeted dollars, I found it odd that both found ways to be "affordable" despite the JCM's shortcomings. I believe programs are required to offer hard truths early. If the program is determined by senior officials to be required despite the increase or decrease in capability or cost, the programs will continue. Failing to articulate a program's current position is negligent. I also believe it is the culture of the DOD to attempt to make the program work in order to "accomplish the mission." Somewhere in the middle of these two paradigms rests the JCM program, along with countless other programs that end before their materiel solution is delivered to the warfighter.

2. Writing and Executing Case Study

According to Newman et al. (2019), the application of case study to teach higher education spans a diverse array of professions ranging from chemistry and automated record-keeping to organizational behavior, marketing, and management. It is most notably used in higher education institutions within fields that self-regulate or are the regulators. As an organization that forces development and key requirements to hold positions within the career field, there is ample reasoning for acquisition professionals to immerse themselves in the case study teaching methodology (Newman et al., 2019).

From what I have learned in developing this project, there is tremendous flexibility to develop case study as instructors see fit in order to better the force. However, for this project, I found that the MICA method may be a more effective way to achieve the objective results that DAU-type courses might require. Table 13 shows comparisons for a number of metrics evaluated between the Harvard method and the MICA method.

Table 13. MICA Versus Harvard Case Method Comparison. Source: Desiraju and Gopinath (2001).

TABLE 2
Impact of Method in Comparing the Harvard Case Method and the McAleer Interactive Case Analysis Method

	HCM	*MICA*
As part of your preparation, to what extent did the nature of class discussion encourage you to		
1. Read case more carefully	5.03	5.72***
2. Analyze the case data more thoroughly	5.16	5.60
3. Seek additional data about the case	3.13	3.64
4. Speak more frequently in class	4.77	5.48**
5. Listen to others and consider their opinions when voicing your own	5.68	6.06
6. Use case details while participating in class	5.29	5.91**
7. Use knowledge of marketing concepts and theories	5.03	5.51
Overall, I found the case discussions useful in applying retailing concepts to a real life situation	5.29	5.36

**$p < .10$. ***$p < .05$.

TABLE 3
Recall of Case Content in Comparing the Harvard Case Method With the McAleer Interactive Case Analysis Method

		HCM		*MICA*	
Case	*Focus of the Case*	*Main focus*	*Other issues*	*Main focus*	*Other issues*
Hill's	Formulating a retail strategy	5.16	4.33	5.03	4.33
Carter's Auto	Implementation of a retail strategy	4.87	4.14	5.5**	4.20
Randall's	Retail pricing	4.77	4.40	5.42	4.38
Filene's	Retail growth and expansion	5.45	4.21	5.67	4.46
King	Non–store retailing	4.43	4.57	4.79	4.81

**$p < .10$.

TABLE 4
Direct Measures of Student Learning in Comparing the Harvard Case Method With the McAleer Interactive Case Analysis Method

	HCM Mean %	*MICA Mean %*
Midterm exam—written case analysis	84.53	84.47
Final exam—written case analysis	83.73	84.87
Class participation for entire semester	47.13	51*

Although the JCM program no longer exists today, the Joint-Air-to-Ground-Missile (JAGM) program does, according to the annual weapon systems assessment conducted by GAO. In the JAGM capacity, the program has adopted the requirement to replace the

Hellfire and longbow missiles, but with different technology capabilities than the JCM. Although the JCM was terminated, it has been essentially renamed to the JAGM and its requirement gap remains similar, but with a smaller technology package. The report finds that the missile seeker technology was finally matured in 2016, basically 14 years following the MDA's decision to launch the JCM into TMRR and later EMD. The technology in the JAGM is reduced compared to the JCM, but a materiel solution for a capability gap, and resource necessitated program, is underway (GAO, 2019). It is amazing that the services have yet to produce a materiel solution to a capability gap identified over 20 years ago, or maybe the JCM program demonstrates the difficulty programs have while operating within the acquisition frameworks, multiple wars, continuing resolutions, and ever-changing priorities.

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